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Evaluation of the repeatability of a sports technique using selected kinematics quantities based on the example of backhand spring

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Abstract

Background: The aim of the study was to determine the changes that occur during a back handspring performed by artistic gymnastics competitors on the basis of selected biomechanical quantities. Material/Methods: The case study included five masterclass artistic gymnastics competitors. The activities were recorded at the frequency of 120 [Hz]. Using the SkillSpector computer software, selected biomechanical variables of the back handspring technique were analyzed. The coefficient of variation was used to evaluate the variability of movement, which, in turn, was used to describe the repeatability of the back handspring technique. Results: Kinematic analysis of the back handspring carried out with the recorded video material enables the qualitative evaluation of the repeatability of the sports technique. The position of the center of mass on the vertical axis determined at borderline points of phases in the back handspring technique was the quantity of highest repeatability. The lowest repeatability was observed in the absolute and relative (movement rhythm) durations of particular phases. Conclusions: It is possible to master the back handspring while maintaining full repeatability of some biomechanical quantities characterizing the movement technique. The assessment of movement repeatability in gymnastics requires further research, with the simultaneous analysis of various biomechanical quantities and a determination of the best methods of comparison.

Keywords

repeatability of movement, artistic gymnastics, back handspring, biomechanics

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D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Evaluation of the repeatability of a sports technique using selected kinematics quantities based on the example of back handspring

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INTRODUCTION

One of the most important aims of technical training in artistic gymnastics is the development of the repeatability of movement both in training and in starting conditions. According to researchers, repeatability is a feature of movement that indicates the level of compatibility of motor functions or of compatibility of particular cycles (in the case of cyclical movements) [1]. It is worth noting that this level of compatibility of motor functions can be determined by the changes that take place in the technique during the activity's performance. In numerous sport disciplines, including artistic gymnastics, a high level of repeatability of motor functions plays a crucial role in obtaining success. To date, the selection of appropriate physical quantities that, when compared to the data of subsequent repetitions of the same activity, would allow the evaluation of the repeatability (variability) of a competitor's movement has been an unsolved problem. The selection of such quantities depends, of course, on the specificity of motor functions performed in a particular sports discipline. When analyzing the repeatability of the classic clean and jerk, Raczek et al. [2] used kinematic variables such as barbell trajectory and values of the angular positions of the knee and hip joints. At the same time, these authors stated that the coefficient of variation accurately expresses the level of the repeatability of movement. On the basis of different variables, it has been demonstrated that more advanced competitors exhibit a lower level of variability of movement than beginners [1]. Sforza et al. [3], who evaluated the repeatability of kicks in traditional karate (mae-geri-keage), came to the same conclusion using three-dimensional movement analysis.

Mastering gymnastic activities in a repeatable way, while at the same time maintaining the accuracy of movement, has many benefits for competitors. This enables further development of the athlete's skill level, gives a possibility of learning new and more difficult elements, increases the possibility of accuracy in competitions, helps in the planning of sports tactics, and improves result predictability. An improvement in competitors' safety when they perform activities, including better protection against injuries, which are very common in artistic gymnastics [4, 5] is an important result of the repeatability of movement.

Researchers claim that the final stage of motor learning is characterized by stability and automatism of a performed movement with only little attention being paid to it [6]. However, as experts in artistic gymnastics observe, mastering activities in an unchangeable way is almost impossible in this discipline [7]. Therefore, it can be stated that the realization of a particular gymnastic element will always be connected to the variability of particular physical quantities characterizing a sports technique. Determining such variability in successive repetitions of a particular activity is also a way to assess the technical level of its mastery and the effectiveness of technical training.

Artistic gymnastics includes a wide range of motor activities that are applied to achieve a high level of mastery. As a result, it plays a significant role in the process of technical preparation. One such activity is the back handspring [8], which is the most common acrobatic element, after the round-off, performed as a driving element for various acrobatic jumping skills [9]. Developing a repeatable technique of performing such an activity makes it possible for a gymnast to focus his attention on more difficult elements performed directly after a back handspring, such as somersaults (in various positions), the "Tsukahara", the "Lyukin" and many more [10]. What is more, a correctly performed back handspring makes it possible to learn more difficult activities on different gymnastic equipment (e.g., the "Yurczenko" vault).

The most common quality assessment methods for gymnastics training activity techniques are trainer and judge observation. Video devices and computer programs augment these methods and make it possible to conduct quantitative analyses [11]. For activities carried out at high speed and short duration, such as the back handspring [12, 13], the accuracy of methods based only on observation decreases because a thorough visual observation and precise analysis are almost impossible. Similarly, testing only on the basis of observation of movement repeatability is also impossible.

The existing literature does not include any scientific papers that explain the issue of variability of technique in gymnastic activities in detail. For that reason, we designed this study to determine the changes taking place during a back handspring performed by artistic gymnastics competitors.

MATERIAL AND METHODS

The research included five gymnasts who were active masterclass competitors of University Club AZS of University of Physical Education (AWF) in Kraków[1]. Table 1 presents the participants' characteristics. The athletes' trainers[2] declared that each participant had completed the process of learning the back handspring. The trainers divided the participants based on the technique each used when performing a back handspring (Table 1). Prior to taking part in the research, which was carried out during a single training session, the gymnasts participated in a typical warm-up, ending with a test performance of a back handspring three times.

Table 1. Characteristics of artistic gymnastics competitors

Gymnast	Age [years]	Height [cm]	Weight [kg]	Training experience [years]	Gymnast's rank basedon the quality of back handspring performance [rank*]
M.Ko.	24	176	71	18	1
M.Ka.	22	173	72	16	2
J.W.	18	172	63	13	5
J.P.	18	170	65	13	3
F.S.	18	172	64	13	4

* Rank no. 1 was assigned to the gymnast with the best back handspring technique

During the research, each athlete performed eight standing back handsprings from which the repeatability of the sports technique was evaluated. Gymnasts performed back handsprings taking turns, each time in the same order and from the same initial position (position with arms up). Springing from the feet was preceded by arm swings. After performing the back handspring, the gymnasts sprung up to a standing position. Motor activities were carried out while preserving training conditions on "Ges" gymnastics mats in a gymnasium of AWF in Kraków.

[1] Division of sports classes and categories applicable in Poland and rules for obtaining particular classes can be found at the website of Polish Gymnastics Association [www.pzg.pl].

[2] Two trainers worked with the gymnasts. The first has the qualifications of a champion-class trainer; the second has the qualifications of a second-class trainer.

The activity was recorded at 120 [Hz] frequency using a Casio Exilim EX-FH25 (CASIO America, Inc., Tokyo, Japan) digital camera, mounted on a tripod, in a plane perpendicular to the direction of a competitor's movement (on the side for competitor's sagittal plane). Before the recording began, elastic adhesive tape was used to mark selected points on the left side of competitors' bodies, as seen from the position of the camera. The majority of those markers determined the position of the rotating axis of selected joints of the upper (shoulder joint, elbow joint, wrist joint) and lower limbs (hip joint, knee joint, ankle joint). The center of the forehead and the chin was also marked. The markers were then used in a ten-point model of the body in the SkillSpector computer program to determine selected kinematic body quantities when performing a back handspring and to conduct a biomechanical analysis of the obtained quantities. Analysis of the diversified movement technique was conducted using phase segmentation of an activity (back handspring), which is presented in Table 2.

Table 2. Phase segmentation of the back handspring

Phases of back handspring	Symbol	Boundaries of particular phases	
		beginning (symbol)	end (symbol)
First phase of support on lower limbs	A–B	Position with arms up, standing to move arms down (A)	Detaching feet from the ground (B)
First phase of flight	B–C	B	Fingers touch the ground (C)
Support on upper limbs phase	C–D	C	Detaching fingers from the ground (D)
Second phase of flight	D–E	D	Toes touch the ground (E)
Second phase of support on lower limbs	E–F	E	Detaching toes from the ground (F)

After the video material was prepared, the following biomechanical variables characterizing the back handspring technique were selected and analyzed in SkillSpector computer program v.1.3.0 (Video4Coach, Odense, Denmark):

1. Duration of back handspring (the total duration of phases A–F) [s].
2. Duration of particular phases of back handspring [s].
3. Movement rhythm – relative duration of particular phases with respect to the total duration of back handspring [%].
4. Position of the center of mass (CoM) on the vertical axis at borderlines dividing particular phases [m].
5. Position of the center of mass (CoM) on the horizontal axis at borderlines dividing particular phases [m].
6. Angular position of the knee joint between the thigh and the lower leg at borderlines dividing particular phases [deg].
7. Angular position of the hip joint between the body trunk and the thigh at borderlines dividing particular phases [deg].
8. Angular position of the shoulder joint between the shoulder and body trunk at borderlines dividing particular phases [deg].

Arithmetic means ($\bar{x}$), standard deviations (SD), minimal and maximal values (Max and Min) were calculated for the selected quantities. The level of variability of the back handspring technique was determined using the coefficients of variation (V) calculated for particular biomechanical quantities. We also determined the average variability of the examined data of the movement technique, calculated as an arithmetic mean of coefficients of variance of particular quantities from the results of all participants.

RESULTS

Table 3 presents the time description of the back handspring from overall (phases A–F) and individual points of view as well as the movement rhythm of the exercise. The duration of the back handspring for all participants ranged from 1.87 [s] (gymnast J.W.) to 2.12 [s] (gymnast M.Ka.). A small variability in the total duration was observed (V < 5%). While gymnasts M.Ko. and J.W. demonstrated the least variability (V = 1.4%), M.Ka. exhibited the greatest variability (V = 2.3%).

The analysis of particular phases revealed that phase D–E (the second phase of flight) was characterized by the greatest variability in each participant. In this phase in gymnasts J.W. V = 16.6%, J.P.: V = 15.9% and F.S.: V = 14.8%. The variability of the two remaining gymnasts was smaller (M.Ko.: V = 7.8% and M.Ka.: V = 8.0%). The smallest coefficients of variation, however, were observed in various phases. M.Ko. and M.Ka. demonstrated the greatest repeatability (the lowest variability) in phases C–D (V = 0.0% and V = 2.3%, respectively), while J.W. and J.P. showed the lowest variability in phases A–B (V = 1.3% and V = 2.0%, respectively). In the case of gymnast F.S., the lowest coefficient of variation was noted in phase E–F (V = 3.1%).

Table 3. Total duration of back handspring (A–F), duration of particular phases and movement rhythm

Gymnast	Phases of back handspring	Time of total movement (A-F) and duration times for particular phases					Movement rhythm of back handspring				
		x̄ [s]	SD [s]	Max [s]	Min [s]	V [%]	x̄ [%]	SD [%]	Max [%]	Min [%]	V [%]
M.Ko.	A–B	1.14	0.03	1.16	1.10	2.3	58.9	0.7	59.4	57.6	1.2
	B–C	0.22	0.02	0.24	0.20	7.2	11.5	0.7	12.3	10.5	6.1
	C–D	0.24	0.00	0.24	0.24	0.0	12.5	0.2	12.7	12.3	1.4
	D–E	0.17	0.01	0.18	0.15	7.8	8.6	0.8	9.6	7.6	9.3
	E–F	0.16	0.00	0.17	0.16	2.4	8.5	0.2	8.7	8.3	1.9
	A–F	1.93	0.03	1.96	1.90	1.4	-	-	-	-	-
M.Ka.	A–B	1.25	0.06	1.31	1.19	4.4	58.8	1.3	60.5	57.6	2.2
	B–C	0.24	0.02	0.27	0.22	7.4	11.4	0.9	12.8	10.4	7.9
	C–D	0.27	0.01	0.28	0.26	2.3	12.6	0.2	12.9	12.4	1.7
	D–E	0.21	0.02	0.23	0.19	8.0	10.1	1.0	11.2	8.9	10.1
	E–F	0.15	0.01	0.16	0.14	4.7	7.0	0.2	7.3	6.8	2.8
	A–F	2.12	0.05	2.18	2.07	2.3	-	-	-	-	-
J.W.	A–B	1.07	0.01	1.08	1.05	1.3	57.1	0.8	58.0	56.2	1.5
	B–C	0.16	0.01	0.17	0.15	5.6	8.6	0.5	9.3	8.0	5.3
	C–D	0.29	0.02	0.32	0.27	7.2	15.6	1.2	17.0	14.6	7.8
	D–E	0.19	0.03	0.22	0.15	16.6	10.3	1.7	11.7	8.0	16.4
	E–F	0.16	0.01	0.17	0.15	6.9	8.5	0.5	9.1	8.0	5.6
	A–F	1.87	0.03	1.92	1.85	1.4	-	-	-	-	-
J.P.	A–B	1.18	0.02	1.21	1.16	2.0	57.2	0.7	58.0	56.0	1.3
	B–C	0.21	0.01	0.22	0.20	6.2	10.2	0.6	11.0	9.6	6.1
	C–D	0.31	0.02	0.34	0.29	6.1	15.1	0.9	16.4	14.0	6.0
	D–E	0.19	0.03	0.24	0.17	15.9	9.2	1.4	11.6	8.0	15.4
	E–F	0.17	0.01	0.18	0.17	5.2	8.4	0.3	8.8	8.0	4.1
	A–F	2.07	0.04	2.12	2.03	1.7	-	-	-	-	-
F.S.	A–B	1.08	0.04	1.14	1.04	3.4	55.9	1.0	57.3	54.6	1.7
	B–C	0.22	0.01	0.23	0.20	6.0	11.2	0.8	12.2	10.0	7.4
	C–D	0.30	0.03	0.35	0.27	10.5	15.7	1.4	17.6	14.3	9.0
	D–E	0.17	0.03	0.19	0.13	14.8	8.8	1.4	10.0	6.7	16.1
	E–F	0.16	0.01	0.17	0.16	3.1	8.4	0.2	8.7	8.2	2.4
	A–F	1.93	0.04	1.98	1.90	1.9	-	-	-	-	-

In four gymnasts (M.Ko., M.Ka, J.P and F.S.), the rhythmic structure of the particular phases of back handspring (the percentage share of a particular phase in the whole activity) was similar. Phase A–B in those competitors was the longest, followed by phases C–D, B–C, D–E and E–F (the percentage share decreased with each subsequent phase). In the case of one gymnast (J.W.), the rhythmic structure was slightly different: A–B, C–D, D–E, B–C and E–F (the percentage share decreased with each subsequent phase). The variability of rhythm (V) in each competitor was highest in phase D–E (the second phase of flight). The greatest coefficient of variance was obtained by J.W. (16.4%).

Table 4 presents the values for the position of CoM on the vertical axis and the horizontal axis at borderline points dividing particular phases of the back handspring. All participants demonstrated low values for the coefficient of variance on all borders of phases; the highest value was observed at borderline point D in gymnast J.W. (V = 4.7%).

On the last two borderline points of the back handspring (E and F), the value of the coefficient of variance of the CoM position on the horizontal axis did not exceed 5%. The highest value of the coefficient of variance of CoM position on the horizontal axis (12.3%) was observed at borderline point B (detaching feet from the ground) in gymnast J.P. and the lowest value was observed at borderline point C (fingers touch the ground) in gymnast M.Ka. (V = 0.9%).

Table 4. Position of the CoM on the vertical axis and the horizontal axis at borderline points of back handspring phases

Gymnast	Borderline points of back hand-spring phases	Position of CoM on the vertical axis					Position of CoM on the horizontal axis				
		x̄ [m]	SD [m]	Max [m]	Min [m]	V [%]	x̄ [m]	SD [m]	Max [m]	Min [m]	V [%]
M.Ko.	A	1.06	0.00	1.06	1.05	0.4	-	-	-	-	-
	B	0.92	0.01	0.93	0.90	1.1	0.52	0.02	0.54	0.50	3.1
	C	0.96	0.01	0.98	0.95	1.4	0.81	0.04	0.86	0.74	5.5
	D	0.96	0.02	0.99	0.95	1.8	1.32	0.06	1.37	1.22	4.6
	E	0.83	0.02	0.85	0.81	2.1	1.65	0.05	1.68	1.56	3.0
	F	1.08	0.01	1.10	1.06	1.3	1.89	0.05	1.94	1.81	2.5
M.Ka.	A	1.05	0.00	1.05	1.04	0.2	-	-	-	-	-
	B	0.92	0.01	0.94	0.90	1.4	0.47	0.02	0.48	0.44	3.7
	C	0.99	0.01	1.00	0.97	1.5	0.78	0.01	0.79	0.77	0.9
	D	1.10	0.01	1.11	1.08	1.1	1.19	0.03	1.24	1.15	2.5
	E	0.90	0.00	0.90	0.89	0.4	1.39	0.05	1.45	1.32	3.6
	F	1.10	0.02	1.12	1.08	1.8	1.48	0.06	1.54	1.39	3.9
J.W.	A	1.00	0.00	1.00	1.00	0.2	-	-	-	-	-
	B	0.82	0.01	0.83	0.81	1.2	0.57	0.03	0.59	0.51	5.5
	C	0.88	0.02	0.90	0.85	2.3	0.77	0.04	0.81	0.71	5.0
	D	1.00	0.05	1.04	0.94	4.7	1.37	0.08	1.49	1.26	6.2
	E	0.84	0.02	0.86	0.80	2.8	1.72	0.06	1.80	1.64	3.7
	F	1.05	0.02	1.08	1.03	1.8	1.91	0.08	2.02	1.81	4.1
J.P.	A	0.99	0.00	0.99	0.99	0.3	-	-	-	-	-
	B	0.83	0.01	0.85	0.82	1.5	0.56	0.07	0.62	0.44	12.3
	C	0.87	0.02	0.88	0.85	1.9	0.90	0.07	0.94	0.78	7.4
	D	0.97	0.03	1.01	0.95	2.7	1.41	0.10	1.52	1.24	7.2
	E	0.80	0.01	0.81	0.78	1.8	1.61	0.07	1.70	1.50	4.3
	F	1.02	0.01	1.03	1.01	0.8	1.71	0.06	1.80	1.63	3.7
F.S.	A	1.01	0.00	1.01	1.01	0.1	-	-	-	-	-
	B	0.89	0.01	0.90	0.87	1.4	0.55	0.03	0.58	0.51	4.8
	C	0.93	0.02	0.95	0.89	2.7	0.85	0.02	0.89	0.84	2.4
	D	0.95	0.02	0.97	0.91	2.4	1.37	0.08	1.49	1.27	6.0
	E	0.79	0.01	0.81	0.79	1.1	1.61	0.07	1.67	1.50	4.3
	F	1.03	0.01	1.04	1.01	1.2	1.72	0.08	1.77	1.59	4.6

Table 5 presents values of angular positions of the three joints (knee, hip and shoulder) at borderline points dividing the particular phases of the back handspring. The highest coefficient of variance for the angular position of the knee joint was observed in gymnast J.P. at a single borderline point (C) and amounted to 8.0%. All remaining values of coefficient of variance for angular position of the knee joint in all participants and at all borderline points were smaller (V < 5%). At the hip joint, the highest value of coefficient of variance was 3.1% (borderline point D – F.S. gymnast); it was 4.1% for the shoulder joint (borderline point B – gymnast J.W.).

Table 5. Angular position of the three joints at borderline points of phases of the back handspring

Gymnast	Borderline points of back handspring phases	Knee joint					Hip joint					Shoulder joint				
		x̄ [deg]	SD [deg]	Max [deg]	Min [deg]	V [%]	x̄ [deg]	SD [deg]	Max [deg]	Min [deg]	V [%]	x̄ [deg]	SD [deg]	Max [deg]	Min [deg]	V [%]
M.Ko.	A	183	3	186	179	1.4	170	3	175	167	1.7	192	3	195	189	1.4
	B	148	4	154	144	2.5	153	4	158	147	2.6	172	5	179	166	3.1
	C	117	5	121	109	4.0	136	4	141	130	3.1	177	7	186	166	4.0
	D	178	2	181	176	1.0	212	6	217	204	3.1	223	3	226	219	1.3
	E	155	4	161	151	2.5	249	3	253	245	1.4	272	3	276	268	1.3
	F	188	3	194	185	1.8	212	3	216	209	1.3	245	7	254	238	2.8
M.Ka.	A	190	1	191	189	0.3	168	2	169	164	1.2	192	0	192	191	0.2
	B	136	1	138	135	0.9	163	4	169	159	2.3	189	1	191	187	0.7
	C	143	4	150	139	2.9	148	2	150	145	1.2	163	2	166	160	1.3
	D	181	1	182	179	0.5	235	5	239	228	2.0	210	2	213	207	1.0
	E	162	4	168	157	2.5	248	2	250	244	0.9	257	4	265	255	1.6
	F	183	2	185	180	0.9	208	1	210	207	0.6	208	2	210	206	0.8
J.W.	A	179	1	179	178	0.3	170	1	171	169	0.6	200	4	205	196	1.9
	B	131	5	137	126	3.5	165	2	167	162	1.0	164	7	170	152	4.1
	C	127	4	131	122	2.9	134	4	139	129	3.0	151	3	154	148	1.8
	D	171	2	174	167	1.5	227	6	234	220	2.7	200	3	202	194	1.7
	E	152	4	157	147	2.9	255	3	259	252	1.1	250	6	262	246	2.6
	F	178	3	182	175	1.5	219	5	223	212	2.1	211	5	219	204	2.6
J.P.	A	187	2	190	184	1.1	166	3	171	162	2.0	188	4	192	183	2.0
	B	146	3	149	140	2.4	166	5	175	163	3.0	182	4	185	175	2.4
	C	126	10	138	110	8.0	149	3	154	147	2.0	159	5	165	153	3.4
	D	173	1	175	171	0.8	241	6	247	232	2.5	215	8	223	203	3.9
	E	170	3	174	166	1.7	247	3	253	245	1.3	275	6	283	267	2.0
	F	182	3	186	178	1.7	210	5	218	206	2.2	241	5	249	234	2.2
F.S.	A	178	1	180	176	0.8	168	2	170	166	1.0	199	2	201	197	0.8
	B	145	2	148	143	1.6	154	2	156	152	1.2	191	3	194	187	1.6
	C	106	3	109	102	2.5	146	3	150	142	2.2	174	4	178	166	2.6
	D	175	2	178	172	1.1	233	7	240	225	3.1	216	3	220	212	1.4
	E	178	2	180	174	1.3	231	3	234	228	1.4	263	6	273	259	2.2
	F	182	2	183	179	0.9	204	4	207	200	1.8	241	5	249	237	1.9

Figure 1 individually presents the coefficients of variance V (calculated as an arithmetic mean of coefficients V from the results of all participants) for all quantities making up the back handspring technique. The highest obtained values were the duration of particular phases (V_{av} = 6.3%) and the movement rhythm (V_{av}= 6.0%). The lowest values of coefficient V were obtained for the CoM position on the vertical axis at borderline points of certain back handspring phases (V_{av} = 1.5%).

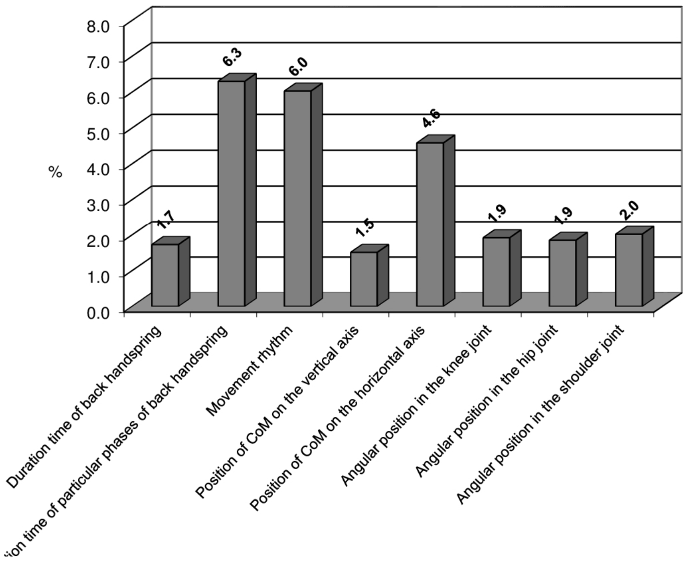

Fig. 1. Variability of particular quantities characterizing the back handspring technique

DISCUSSION

The analysis of variance of the selected movement technique quantities revealed that the gymnasts' activities were characterized by a high level of repeatability in the back handspring in terms of duration of the whole activity as well as kinematic variables such as the CoM position on the vertical axis, the CoM position on the horizontal axis, and the angular position of the knee, hip, and shoulder joints, determined at the borderlines of phases of this activity. The CoM position on the vertical axis turned out to be the most repeatable technique variable (V_{av}= 1.5%). The high repeatability of this variable probably results from the stable height of each participant and their CoM position from the ground. Higher variability of the CoM position on the horizontal axis (V_{av}= 4.6%), however, might be influenced by the different speed with which each gymnast performed the activity. However, it needs to be noted that the subject of the research was the analysis of an activity that is relatively easy for the participants; therefore, in the course of training, athletes do not work on improving their technique in regard to this movement. Conducting similar research in a group of younger gymnasts who have not fully mastered the back handspring would probably show greater variability of the investigated quantities. Higher repeatability characterizing competitors with greater training experience probably results from deliberate changes taking place in the movement technique as a result of means and methods used in the improvement process, which has been presented by Bradshaw et al. [14] and Williams et al. [15] in the example of other gymnastics activities.

We did not find that the gymnasts with the longest training experience or the best back handspring technique (evaluated by trainers) were characterized by the best repeatability with respect to all analyzed data. However, it is worth noting that the only coefficient of variability amounting to 0.0% in phase C–D (support on the upper limbs phase), indicating full repeatability, was obtained by M.Ko., the gymnast with the longest training experience (18 years).

Despite the trainers' declaration that the participants of the study had ended the process of back handspring learning, the averaged coefficients of variance determined for the rhythm and duration of particular phases obtained higher values than other quantities. In the case of those two quantities, the highest variability in each gymnast was noted in the same phase, namely phase D–E (the second phase of flight). For the rhythm of this phase, it can be noted that the greater coefficient of variance corresponds to a higher rank related to the technique used in back handspring (weaker technique). It is also worth highlighting that three gymnasts (J.W., J.P., F.S.) who were characterized by higher coefficients of variability with respect to time and rhythm in phase C–D (support on the upper limbs phase) with respect to two other participants (M.Ko. and M.Ka.), also achieved much higher values of this coefficient in the subsequent phase (D–E, the second phase of flight). This may highlight the influence of the technique used in the previous phase on the subsequent phase, especially if the former phase consisted of springing from the lower limbs and the latter was the flight phase. Therefore, it seems that in all participants the variability of the preceding phase influenced the variability of the subsequent one. This suggests that the better-trained gymnasts had better repeatability of some quantities of the gymnastic activities technique. However, unequivocal confirmation of this statement requires further research with a larger group of gymnasts. It is important to note that in the training process, there exist possibilities to improve movement rhythm, as discussed by Wang [16].

The results point to the conclusion that using various physical quantities at the same time in order to obtain a full "image" of a sports technique is necessary. An identical conclusion can be made with regard to the assessment of the repeatability of gymnastic activity techniques. The selection of the variables to study variability should be the subject of further research and joint discussion between scientists and practitioners (trainers, judges, competitors). Small modifications can be made to the group of quantities, including time components and being limited only to determine rhythm, for the benefit of selecting other quantities, which have not been used in this paper. This is justified by the fact that components of rhythm include the duration of the whole activity and the duration of individual phases. Rhythm is a characteristic that is assimilated and stabilized during the practical learning of movements. Additionally, according to Schmidt and Wrisberg [6], Wang [16] and many other authors, a decisive factor of effective motor learning is mastering the rhythm of a particular movement. Research shows that repetitively mastered motor activity is characterized by maintaining a specific rhythmic structure, even when its total duration changes [17, 18]. This means that higher or lower speeds for a particular movement and its longer or shorter duration do not influence the changes in the time proportions of particular phases in the structure of the whole activity [6, 19]. However, it can be stated that any imbalance of rhythm will negatively influence the quality of the performed movement, even if the total duration is similar. Therefore, it may be worth replacing some absolute quantities (e.g., position, angular position) with relative values after additional analysis, so that participants' height and length of their body segments do not influence the distortion of result analysis during participant comparison. It would also be a good idea to supplement the results by carrying out an analysis of the CoM velocity and the angular velocity in selected joints in order to determine their importance in the repeatability of movement and influence on its variability.

In this paper, as in Raczek et al. [2], the coefficient of variability was used to evaluate the repeatability of movement. Sforza et al. [3, 20] calculated the standard deviation to assess the repeatability of different movements in traditional Shotokan karate. Thus, scientists dealing with similar subjects should be encouraged to search for different coefficients that can better express the "level" of repeatability of movement specified in the definition.

Discussing the issue of repeatability of movement also deserves mention of other significant aspects related to gymnastics training. Above all, attention should be paid to the risk of injury resulting from a high level of repeatability of movement if the activity is incorrectly mastered. That is why in the process of movement teaching, above all, one should aim to master a particular movement in the correct manner and then strengthen it by obtaining a high level of repeatability.

CONCLUSIONS

In the research we found that the kinematic analysis of the back handspring using recorded video material enables qualitative assessment of the repeatability of a sports technique. The position of CoM on the vertical axis determined at borderline points of the phases was the back handspring technique quantity of greatest repeatability. High repeatability was also obtained for the following variables: the total duration of back handspring and angular positions of the knee, hip and shoulder joints determined at borderline points. The lowest repeatability was in the absolute and relative (movement rhythm) duration of particular phases. It is possible to master the back handspring while maintaining full repeatability of some biomechanical quantities characterizing the movement technique. The assessment of movement repeatability in gymnastics requires further research, with the simultaneous analysis of various biomechanical quantities and a determination of the best methods of comparison.

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