Phase portrait of control movements – one of the criteria of technical skill of an athlete

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Abstract

Objective of the study was to develop an integral criterion of an athlete's technical skill and a computer application for constructing a phase portrait of sports exercises.

Methods and structure of the study. The research instrumental base is video materials of gymnastic exercises, computer tools for processing research results using the MatLab software environment. Performer: A. Bergovin, Master of Sports in artistic gymnastics, Republic of Belarus. Two revolutions were performed in a row, which were compared with each other based on phase portraits.

Results and conclusions. It was revealed that the deformation of the kinematic control structure is most significant in changing the area of the phase portrait and varies within 15-30% of the area of the original image, which, however, does not lead to a significant restructuring of the technical basis of the motor action and makes it possible to implement the target setting of the exercise. Amplitude changes in executive function are less significant in solving a motor task than the rate of change in the joint angle. A comprehensive «Kinematic Control» functionality has been developed, which allows for an integral assessment of the athletes technical skill.

Keywords: *trajectory of the biomechanical system, phase portrait, gymnastic exercises.*

Introduction. In the field of biomechanics of physical exercises, there are a few studies in which attempts have been made to assess the technical skill of an athlete on the basis of an integral indicator that comprehensively characterizes the quality of mastering a motor skill in the form of a phase portrait that determines the kinematic state of control of the biomechanical system [2, 4, 5]. In this regard, a hypothesis has been defined that the assessment of the athlete's biomechanical state, based on the analysis of the phase portrait of control movements at the kinematic level, will make it possible to give an integral assessment of the athlete's level of technical skill.

Objective of the study was to develop an integral criterion of an athlete's technical skill and a computer application for constructing a phase portrait of sports exercises.

Methods and structure of the study. Computer methods for constructing and comparing images and video recording of sports exercises were used. Technical actions in the hip and shoulder joints of a gymnast in a large back rotation on the crossbar were analyzed. Performer A. Bergovin, master of sports in artistic gymnastics, Republic of Belarus. Two revolutions were performed in a row, which were compared with each other based on phase portraits. In the first revolution, a motor task was set: to perform the exercise while achieving the maximum linear speed of the general center of mass of the athlete's body in its upper part. In the second revolution, the motor task of achieving maximum speed was not set for the athlete.

Results of the study and discussion. The main results of the study were: developed computer technology for constructing a phase portrait of sports exercises in the MatLab software environment, visualization of a phase portrait of an athlete's control movements, computer methods of comparison based on the similarities and differences of «standard»-«performer» phase portraits.

Computer technology for constructing a phase portrait of sports exercises. The «input» block of the computer program receives information about the trajectory positions of the links of the biomechanical system in the form of a two-dimensional array of generalized coordinates – Q (n, m), where n is the number of video frames of the exercise, m is the number of model links. Calculations and construction of phase portraits «Kinematic control» are performed in the MatLab software environment, developed by a computer program.

Visualization of a phase portrait of an athlete's control movements. Along the Ox axis of the Cartesian coordinate system (DCS), the value of the control function is plotted, presented in the «degree» dimension and calculated as the difference in the generalized coordinates of the biosystem, where i varies from 1 to n, and j – from 1 to m. Along the ordinate axis DSC is the speed value of the control function in the dimension «rad/s». The resulting points are the vertices of the polygon, characterizing the state of kinematic control in the competitive exercise at the points of the j-phase portrait. In Fig. Figure 1 shows options for computer construction of phase portraits for visual analysis of images using the 'FaceAlpha' function (Fig. 1.1-1.4) and computer comparison based on a binary image (Fig. 1.5-1.6).

The numerical value of similarities and differences in the athlete's technical actions was assessed using computer methods in the MatLab software environment.

Computer methods for assessing image characteristics. In line with the thematic focus of the study, we paid priority attention to two basic categories of information indicators of similarity and difference between images: the geometric shape of the objects being compared and comparison criteria.

The geometric shape of the compared objects was characterized by visual and numerical assessment of the parameters of the main spatial characteristics of the phase portrait using the corresponding functions [1, 3] of the MatLab software environment: image contour (markerless - Fig. 2.1; marker - Fig. 2.2), area (in the dimension of the original data – Fig. 2.3; in pixels – Fig. 2.4), perimeter, center of the figure (Fig. 2.5), maximum and minimum control and speed limits (bounding rectangle – Fig. 2.6), orientation of the major axis (Fig. 2.7), ellipsoid (Fig. 2.8).

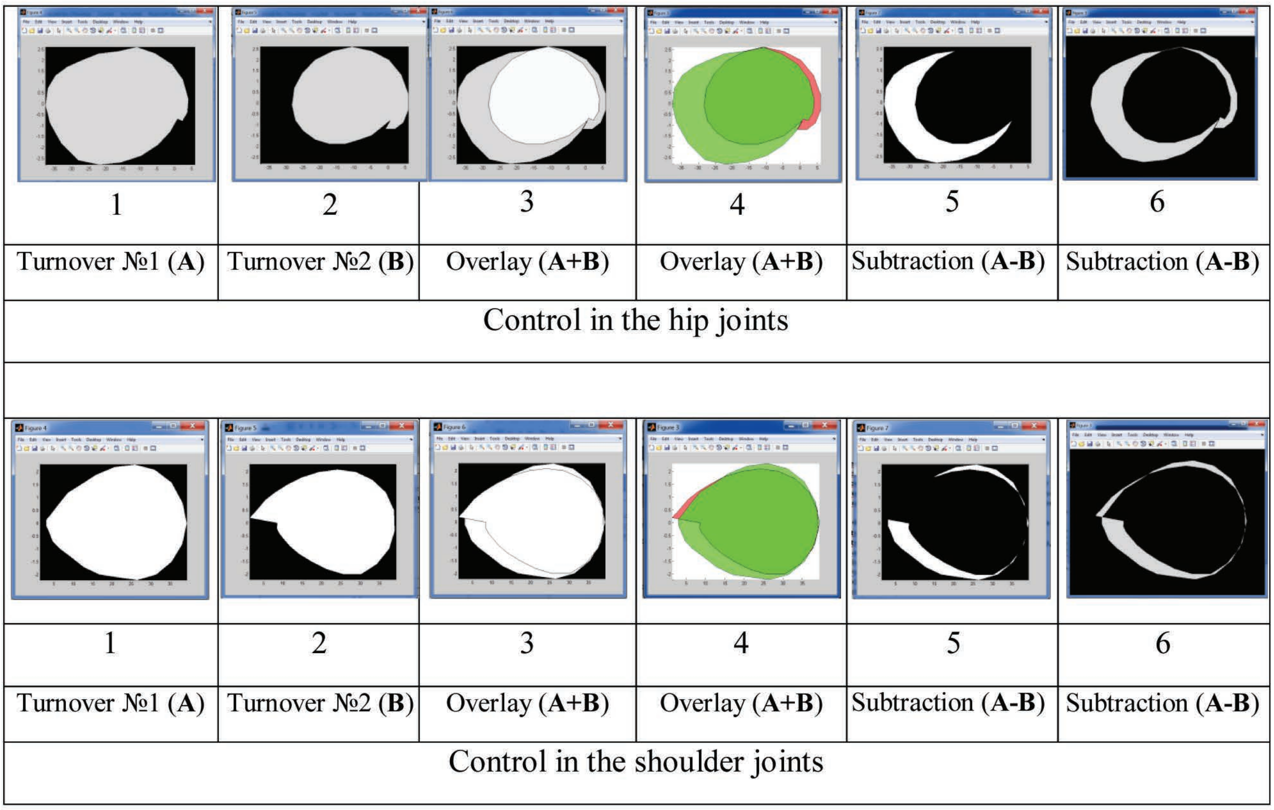

Fig. 1. *Phase portrait – control in the hip and shoulder joints in the first (A) and second (B) large revolutions back on the crossbar*

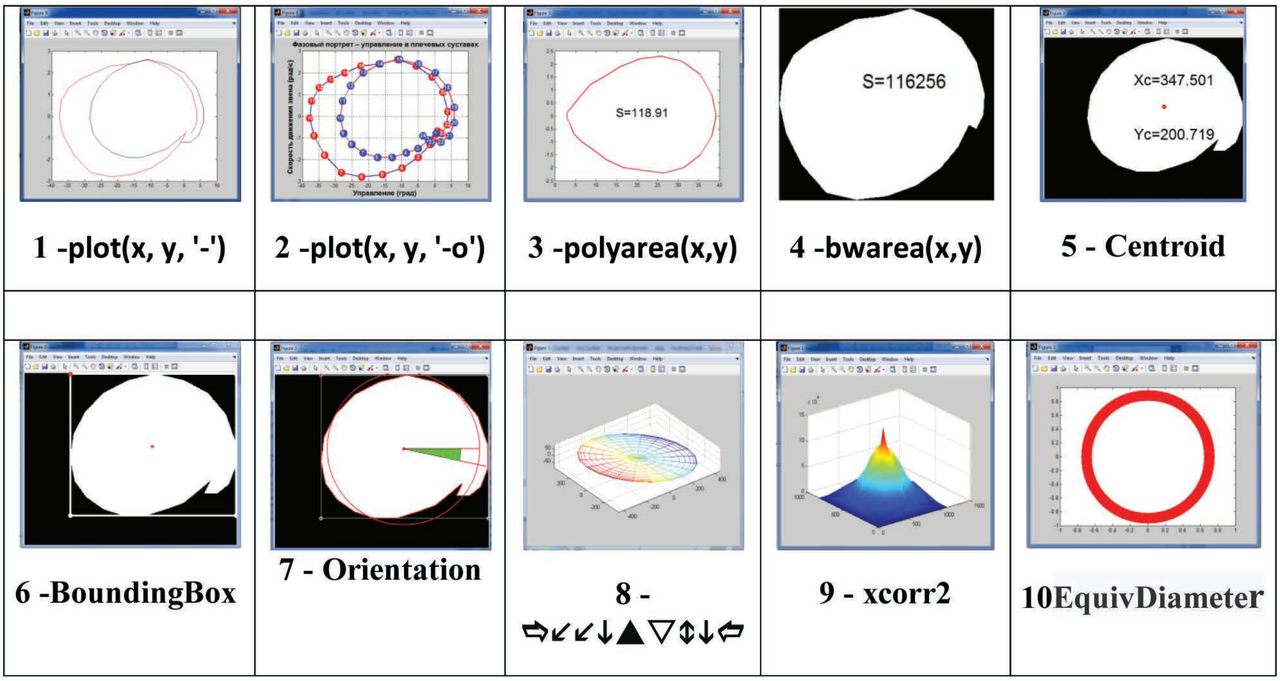

Fig. 2. *Elements of the geometric shape of phase portraits of a biosystem and the functions of their representation by the MatLab software environment*

Elements of the phase portrait of the kinematic control of the biosystem were visualized and assessed using functions and commands of the MatLab software environment, designated:

x, y – vectors defining the vertices of the polygon in the 2D area;

plot (x,y,'-') – function of plotting a polygon without a marker outline;

plot (x,y,'-o') – function for constructing the marker contour of a polygon;

polyarea (x,y) – a function that calculates the area of a polygon based on given vertices in the dimension of the DSC axes;

bwarea (BW) – estimates the area of objects in a binary BW image in pixel dimension;

Parameters of deformation of the phase portrait «Kinematic control» in large revolutions back on the crossbar

Element	Turnover 1				Turnover 2				The relationship between turnovers			
	Management (U)				Management (U)							
	1		*2*		*1*		*2*					
1	2		3		4		5		6		7	8
Square	S_1	118,9	S_2	167,7	S_3	102,5	S_4	117,9 S_4/S_2	S_3/S_1	0,862	Management 1	Management 2
									0,703			
Perimeter	P_1	277,7	P_2	311,8	P_3	264,4	P_4	253,5	P_3/P_1	0,95		
									P_4/P_2	0.81		
Radius equivalent	Rs_1	205	Rs_2	243	Rs_3	190	Rs_4	204	Rs_3/ Rs_1 0,927	Rs_4/Rs_2 0,840		
Limits on horizontal	X_{1min}	2,9	X_{2min}	-37,8	X_{3min}	1,4	X_{4min}	-28,5	$X_{3,4min}-X_{1,2min}$		1,5	9,3
	X_1y_{mn}	26,4	X_2y_{mn}	-22,1	X_3y_{mn}	30,2	X_4y_{mn}	-17,3	$X_{3,4}y_{mn}- X_{1,2}y_{mn}$		3,8	4,8
	X_1y_{mx}	25,9	X_2y_{mx}	-11,1	X_3y_{mx}	24,1	X_4y_{mx}	-10,7	$X_{3,4}y_{mx}- X_1y_{mx}$		-1,8	0,4
	X_{1max}	39,2	X_{2max}	4,0	X_{3max}	38,9	X_{4max}	5,9	$X_{3,4max}-X_{1,2max}$		-0.3	1,9
Amplitude	L_1	36,3	L_2	41,8	L_3	37,5	L_4	34,4	$L_{3,4}- L_{1,2}$		1.2	-7,4
Limits on verticals	Y_{1min}	-2,2	Y_{2min}	-2,8	Y_{3min}	-2,0	Y_{4min}	-1,9	$Y_{3,4min}-Y_{1,2min}$		0,2	0,9
	Y_{1max}	2,3	Y_{2max}	2,6	Y_{3max}	2,1	Y_{4max}	2,6	$Y_{3,4min}-Y_{1,2min}$		-0,2	0,0
Amplitude	H_1	4,5	H_2	5,4	H_3	4,1	H_4	4,5	$H_{3,4}- H_{1,2}$		-0.4	-0,9

graindata (2) – characterizes the image and coordinates of the center along the Ox and Oy axes of the DSC with the options: graindata (2). Centroid(1), graindata(2).Centroid(2);

graindata(2). BoundingBox (1-4) – image boundaries are extracted.*Comparison criteria* by which the similarities and differences of phase portraits were assessed:

1. The ratio of the image areas of the standard and the performer.
2. Amplitude of limit changes.
3. The criterion for two-dimensional comparison is the coefficient xcorr 2 (Fig. 2.9).
4. Radius of a circle equivalent to the image area.

The main numerical solutions for a gymnast's implementation of various motor tasks in a large backward rotation on the crossbar are given in the table.

The dimension of the indicators corresponds to the input data (the Ox DSC axis is degrees, the Oy DSC axis is rad/s).

Characteristics of shape deformation of phase portraits. Deformation of the shape of phase portraits in the DSC metric can be carried out both along the numerical axis Ox (control of kinematic changes in the angle in the joint) and along the Oy axis (velocity of kinematic control in the joint).

The discrepancy between the characteristics of the phase portrait in the first (S1, P1, L1, H1) and second (S2, P2, L2, H2) exercises is (Table 1): area (S1÷S2) – 14%-30%, perimeter (P1÷P2)–5%-20%, control amplitude (L1÷L2) – 2,2%-17,7%, control speed amplitude (H1÷H2) – 8,9%-16,7%. Consequently, the functional, which comprehensively characterizes the magnitude of the deviation of the biomechanical characteristics of movement from the "ideal model", can

$$F = abs(S_1 - S_2) + abs(P_1 - P_2) + abs(L_1 - L_2) + abs(H_1 - H_2).$$

be represented in the form.

The functionality (F) is complex and includes the following elements: S – area, P – perimeter, L – maximum and minimum control limits, H – control speed limits. Digital indices correspond to objects: 1 – standard, 2 – performer. The more the functionality is minimized and approaches zero, the less differences in the exercise technique of the compared athletes.

C**onclusions.** It was revealed that the deformation of the kinematic control structure is most significant in changing the area of the phase portrait and varies within 15-30% of the area of the original image, which, however, does not lead to a significant restructuring of the technical basis of the motor action and makes it possible to implement the target setting of the exercise. Amplitude changes in executive function are less significant in solving a motor task than the rate of change in the joint angle. A comprehensive «Kinematic Control» functionality has been developed, which allows for an integral assessment of the athlete's technical skill.

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