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Symmetry and Asymmetry of Kinematic Structure of Natural Human Locomotion

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Abstract

Background/Objectives: Study of symmetry in the structure and functioning of human body does not have a long-term history. In 1848 L. Pasteur discovered symmetric interrelations, thereby laying the groundwork of the molecular asymmetry doctrine, which was the first stage in the intensive study of laterality of organic compounds. References to correlation between symmetry and asymmetry are fragmentary in human physiology. Modern literature does not analyze the study of kinematic structure of a human being motion as a symmetry object. This article is aimed at determining the occurrence of dynamic symmetry and dynamic asymmetry of the kinematic structure of natural locomotions in the course of sports perfection and individual development of a human being in the ontogeny. **Methods:** Modern methods of registration of kinematic characteristics offer the possibility of objective assessment of the kinematic structure form of natural locomotions. This circumstance enables to apply the systematic and symmetrical method of cognition of biological processes for studying kinematic structure of human motion. **Findings:** Study of kinematic structure of natural locomotions has been carried out in this article as exemplified by squatting of powerlifters and children aged 5 and 6. Kinematic characteristics were registered on the basis of optical system of three-dimensional video analysis of movements. "Movement Video Analysis" software enables registration of change of angular movements in joints. It was found that spatiotemporal movements in joints during squats done by powerlifters occur in the form of dynamic symmetry and dynamic asymmetry. Dynamic symmetry of joint movement is characterized by kinematic structure, when spatiotemporal angular movement during joint extension is a reverse spatiotemporal angular movement during flexion. Violation of dynamic symmetry reveals in case of increase in poundage by more than 60% of the maximum. In the course of individual development dynamic symmetry of angular movements in ankle, knee and hip joints is formed in a heterotropic mode. Dynamic symmetry of spatiotemporal angular movements in knee joints is formed by six years of age. Dynamic asymmetry is characteristic of this and angular movement in hip and ankle joint. **Application:** The obtained data will enable to develop methods for assessing quality of realization of human movement skills on the basis of systematic and symmetrical approach.

Keywords: Kinematic Structure, Natural Locomotions, Symmetry/Asymmetry

1. Introduction

The phenomenon of a human being can be understood and explained only when it is considered as an integral structure which is one of components of nature functioning on the basis of natural regularities. Among the rules of the natural world functioning, such as the rule of correspondence between stability and changeability of the defining role of influence of external conditions on this material structure, dynamic balance, etc., scientists place special emphasis on the rule of harmony and disharmony which at the same time reflects regularities of dialectics, structure and functioning of complex systems. Defining harmony as a system state (conformability, order, commensurability, steadiness, spatiotemporal integrity), one should note that its characteristics lie within the integrity.

Struggle of harmony against its opposition – disharmony – is a struggle eliminating each other and relating not to internal interaction of system elements, but to outer

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characteristics of existence of the system itself. “Harmony” definition can be referred to any functional system, which has functional unity and interrelation of levels. Harmony is derived from the dialectic unity of stability and changeability. Symmetry is a principal sign of stability. Symmetric method of study of physiological mechanisms has become wide-spread in modern researches.[1-20]

Study of a human being from the perspective of unity of symmetry-asymmetry is of peculiar interest, since one cannot find such divergence of asymmetry functions of symmetric sides of the body in any animal, which is lower than a human being on the evolutionary ladder. Mirror symmetry of the right and left sides of the body is violated by the right-handedness associated with divergence of functions of sensorimotor areas of the hemispheres. However, anatomic symmetry of the left and right cerebral hemispheres accompanied with sharp asymmetry in their activities is even more mysterious. Studies of and others prove conclusively the existence of dextrocerebral and sinistrocerebral strategy of thinking, sharp inequality of hemispheres in the mental activity support. If consistency, sameness and invariability to the described objects and manifestations are taken as symmetry of a theoretical system, then development of scientific knowledge may be defined as transition towards symmetry (asymmetry-symmetry). Therefore, symmetry-asymmetry are not just general scientific categories, but a paired category of cognition. At the same time, references to the correlation between symmetry and asymmetry are fragmentary in human physiology. In particular, study of kinematic structure of a human being motion as a symmetry object is not subject to analysis.

The kinematic structure represents spatiotemporal order of angular movements in kinematic chains of human motor apparatus. Application of modern methods of recording kinematic characteristics provides an opportunity to make an objective assessment of the kinematic structure form of natural locomotions and changes thereof in the course of age-related and sports development. This position allows applying the paired method of cognition of biological processes in “symmetry-asymmetry” organism for the purpose of studying mechanisms for regulation and development of human motor function in the ontogeny. Study of the above methodological approaches to application of systematic and symmetry method of studying changes in the kinematic structure of natural locomotions has made it possible to formulate a hypothesis of the research.

2. Concept Headings

Hypothesis of the research laid in supposition that the kinematic structure of natural human locomotions in the course of individual development and sports perfection can appear in the form of dynamic symmetry and dynamic asymmetry.

The purpose of the study is to determine the occurrence of dynamic symmetry and dynamic asymmetry of the kinematic structure of natural locomotions in the course of sports perfection and individual development of a human being in the ontogeny.

Tasks of the study are:

- to determine kinematic characteristics of natural human locomotions in the course of sports perfection and individual development in the ontogeny;
- to establish the parameters of dynamic symmetry and dynamic asymmetry occurrence in the kinematic structure of natural locomotions in the course of sports perfection and individual development of a human being in the ontogeny;
- to find the symmetry violation of the kinematic structure of natural locomotions in the course of sports perfection;
- to determine the procedure of forming symmetry of the kinematic structure of natural human locomotions during the period of establishment thereof in the course of individual development in the ontogeny.

3. Result

Kinematic characteristics of squatting done by children of senior preschool age (5-6 years) and powerlifters have become an object of the study. The three-dimensional movement video analysis system, which allows studying kinematic characteristics of human motion, serves as an objective method to obtain such information.

The kinematic characteristics of squatting with a bar have been studied at the occupational biomechanics laboratory at the premises of “Zdorovye” Center of the Adygea State University. 16 athletes and 60 children aged 5–6 participated in the experiment. Athletes did squats with poundage of 50%, 60%, 70%, 80, 90%. Children did four squats in a row at a free pace.

Kinematic characteristics were recordered by means of optical system of the three-dimensional video analysis of movements. The hardware component of the “Movement Video Analysis” complex consists of two video cameras, two illumination lamps, a test-object, reflective markers, a computer, a video capture board which records footage on a computer hard disk drive.

The software component of the complex performs the following operations:

- shooting of movements at 50 fps rate;
- automatic processing of marker coordinates on a human body;
- graphic display of all recorded kinematic information.

The software of "Movement Video Analysis" complex gives an opportunity to record change of joint angles, angular velocities, angular accelerations, to make a comparative analysis of the results of studying several or one research subject in different periods of time, the results being kept in the study database. In order to register kinematic characteristics of motion, the reflective markers of 2.5 cm in diameter, which reflect the directional light, were placed on a test subject on the lateral side of the body in the area of the center projection of shoulder, hip, knee, ankle, metatarsophalangeal joints and heel. The movements of a test subject were recorded by two video cameras located at a distance of about 6 m from the shooting location at an angle of 60° toward the test subject. The backlights, which illuminated the reflective markers on the hands of the test subject, turning them into bright spots, which allowed clear video recording, were located behind the cameras (Figure 1). Video recordings were processed by means of Video Motion_ 3D Software Package.

Angular movements in ankle, knee and hip joints of powerlifters in the course of squatting have been recorded.

Figure 1. Registration of kinematic characteristics.

It was found that the graphical trajectory of angular variation in knee joint during squatting with poundage of 50–60% represents a geometric parabola, the left branch of which characterizes flexion of joint, and the right one – extension (Figure 2). In accordance with the rules of parabola construction, temporal sequence of a joint extension is a reverse sequence of flexion. The accuracy of occurrence of such relationship increases when flexion transition is approaching extension, which can be seen on the diagram at the point where the parabola branches approach its vertex. Decrease in accuracy of this relation occurs at the point of transition from the initial position to the start of motor action realization and at the transition of the concluding part of the motor action to the final position, i.e. at the transitions of activity into locomotion and vice versa. The diagram below describes this phenomenon at the moment of the biggest divergence of the parabola branches.

Reverse spatiotemporal order of a joint extension in relation to flexion is revealed in the motion of knee, ankle and hip joints of all test subjects in overcoming poundage of up to 60%. This refers rather to the predominant occurrence which is the nearest to the absolute one than to absolutely exact occurrence of such relation. Besides, the closest approach to exact occurrence of such a relation is characteristic of angular movement in the knee joint.

Increase in the poundage up to 70% and more, up to 80% and 90%, results in the change of the order of angular movements. Relation, under which the spatiotemporal order of angular movements in case of the joint extensions is a reverse spatiotemporal order of joint flexion, is violated. The diagram of angular movements shows this effect as a horizontal stretching of the middle of the right branch of the parabola (which is characteristic of the order of joint extension) (Figure 3), which suggests increase in the time of a joint extension, while preserving the time of flexion. The more the poundage is, the more distinct such trend is. At the same time, the revealed changes do not affect the initial period of extension where the reverse order of extension with respect to flexion is maintained.

Thus, the study of the revealed changes through the prism of systematic and symmetrical approach makes it possible to find that the form of the kinematic structure, under which the spatiotemporal order of angular movements during joint extension is a reverse spatiotemporal order of angular movements during flexion, can be taken

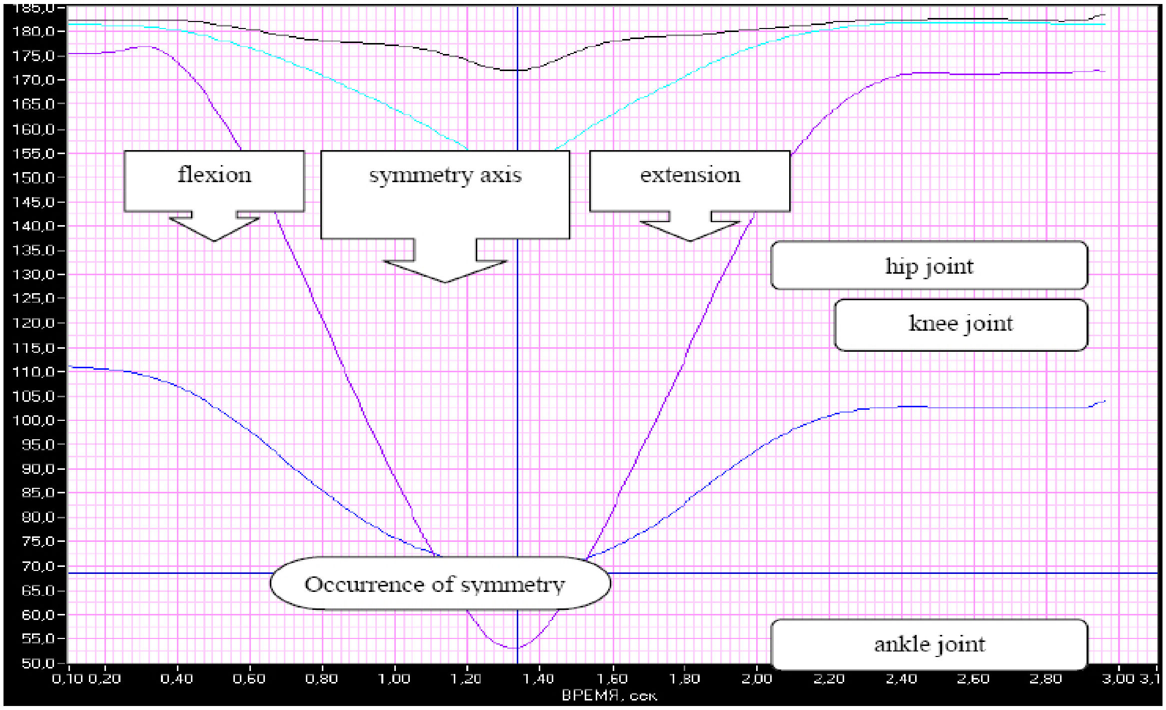

Figure 2. MAngular movements in hip, knee and ankle joint during squats with 50% poundage. (Igor Yermilov, Master of Sports)

Figure 3 Angular movements in hip, knee and ankle joint during squats with 90% poundage. (Evgeniy Ivantsov, Master of Sports)

as an occurrence of dynamic symmetry of a joint movement. All other forms of spatiotemporal order of angular movements are examples of dynamic asymmetry.

The study has enabled to determine some positions which define occurrence of dynamic symmetry in the kinematic structure of angular movements during squats done by the powerlifters:

- the spatiotemporal order of joint movement during squats is expressed in two forms: dynamic symmetry and dynamic asymmetry;
- dynamic symmetry of joint movement is characterized by the kinematic structure, whereby the spatiotemporal order of angular movements during the joint extension is a reverse spatiotemporal order of angular movements during the flexion;
- the graphical trajectory, which characterizes occurrence of dynamic symmetry of joint movement, has a form of a parabola;
- the stability of occurrence of dynamic symmetry in joint movement is observed up to overcoming of 60% poundage;
- dynamic symmetry of joint movement is violated in case of change to the spatiotemporal order of extension;
- the spatiotemporal order of the angular movement in case of joint flexion remains stable in case of all applied kinds of poundage;
- increase in poundage by more than 60% of the maximum causes the transition of the dynamic symmetry into the dynamic asymmetry. Such situation is characteristic of athletes of different level, in particular, Candidate Masters of Sports and Masters of Sports. Therefore, the point of transition from the dynamic symmetry of joint movement into the dynamic asymmetry is subject to the percentage of poundage overcome and not subject to the level of sports mastery.

Thus, the above provisions allow concluding that the dynamic symmetry and dynamic asymmetry are the base forms of the spatiotemporal order of joint movement during powerlifting squatting. However, their formation is laid prior to the start of sports perfection – during establishment of natural locomotions in the earlier period of the ontogeny. In this regard, in order to determine the mechanism for formation of the dynamic symmetry of joint movement, the kinematic characteristics of angular movements in the course of squatting done by five- and six-year-old children are studied. Such age is the period of intensive development of natural locomotions.

Graphic presentations of angular movements in ankle, knee and hip joints have been studied. The research results suggest dividing the participants into two groups (Table 1). The first group includes the test subjects, whose kinematic structure in joint movement is characterized with occurrence of dynamic symmetry, whereby the spatiotemporal angular movement during joint extension is a reverse spatiotemporal angular movement during flexion. Graphic trajectories of changes of angles of the studied joints represent a geometric parabola, the right branch of which characterizes the temporal order of joint flexion, and the left branch – a temporal order of joint extension (Figure 4).

Thus, occurrence of the dynamic symmetry of spatiotemporal order of knee joint movement is characteristic of 67% of 5-year-old children and 86% of 6-year-old children.

It was found that the dynamic symmetry of angular movement of ankle and hip joints are formed in the later age. Thus, there are no 5-year-old children, whose spatiotemporal order of angular movements during ankle and hip joint extension is a reverse spatiotemporal order of angular movements during ankle and hip joint flexion, while there are 3% and 2%, respectively, of the total amount of the 6-year-old children (Table 1).

The second group includes 5-year old children and 6-year old children, whose kinematic structure of joint movement is characterized by occurrence of dynamic asymmetry. It can appear in two forms with respect to the knee joint. The first type is characterized with violation of the temporal order of angular movements during joint extension (Figure 5). Such situation can be found in case of powerlifters when overcoming poundage of more than 70%.

The second type is characterized with violation of the temporal order of angular movements during joint flexion (Figure 6). Such peculiarity is revealed only in the child age, there were no such facts during testing of an athlete. Reliable changes in the temporal order of angular movements during joint flexion do not occur even in the course of application of near extreme poundage.

All test subjects of the second group demonstrate the first and the second type of angular movements during the first squat, 72% of them – during the second squat and 25% of test subjects – during the third and the fourth squat. Such situation makes it possible to conclude that,

Table 1. Division of experiment participants aged 5 and 6 years into groups on the basis of formation of order of angular movements in ankle, knee and hip joints.

Groups / Joints		First Group (occurrence of the order of angular movements in the form of dynamic symmetry)	Second Group (occurrence of the order of angular movements in the form of dynamic asymmetry)	
			First Type	Second Type
Hip Joint	5 years	0 %	100%	
	6 years	2%	98%	
Knee Joint	5 years	67%	23.6	9.8
	6 years	86%	9.4	4.2
Ankle Joint	5 years	0%	100%	
	6 years	3	97%	

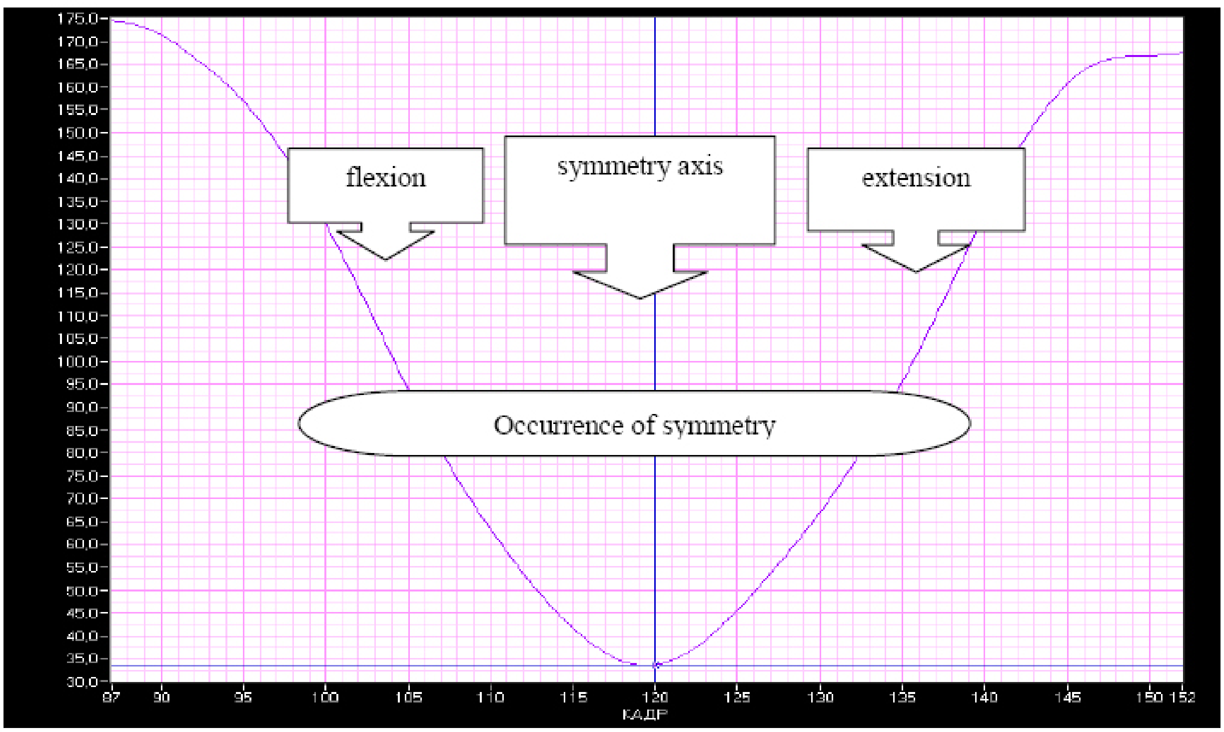

Figure 4. Change of the angle in the knee joint characteristic of the first group of test subjects.

on the one part, there is no stability in the temporal order of angular movements in the knee joint, and, on the other part, correction of the temporal order of angular movements appears towards forming the dynamic symmetry.

Violation of the dynamic symmetry of the temporal order of angular movements characterizes movement errors which are demonstrated by athletes only in case of application of poundage exceeding 60% of the maximum. Children demonstrate such violations both in case of extension and in case of flexion of joints. In 87% of all cases, violation of the order of angular movements during a knee joint flexion does not result in violation of the order of angular movements during its extension. In the second group the number of children with the first type of violation of the order of angular movements at the age of five totals to 23.6%, and children with the second type of violation of the order of angular movements make 9.4%. By the age of six this quantity is reduced to 9.8% and 4.2%, respectively. Thus, the stability of occurrence of the dynamic symmetry of the spatiotemporal order of

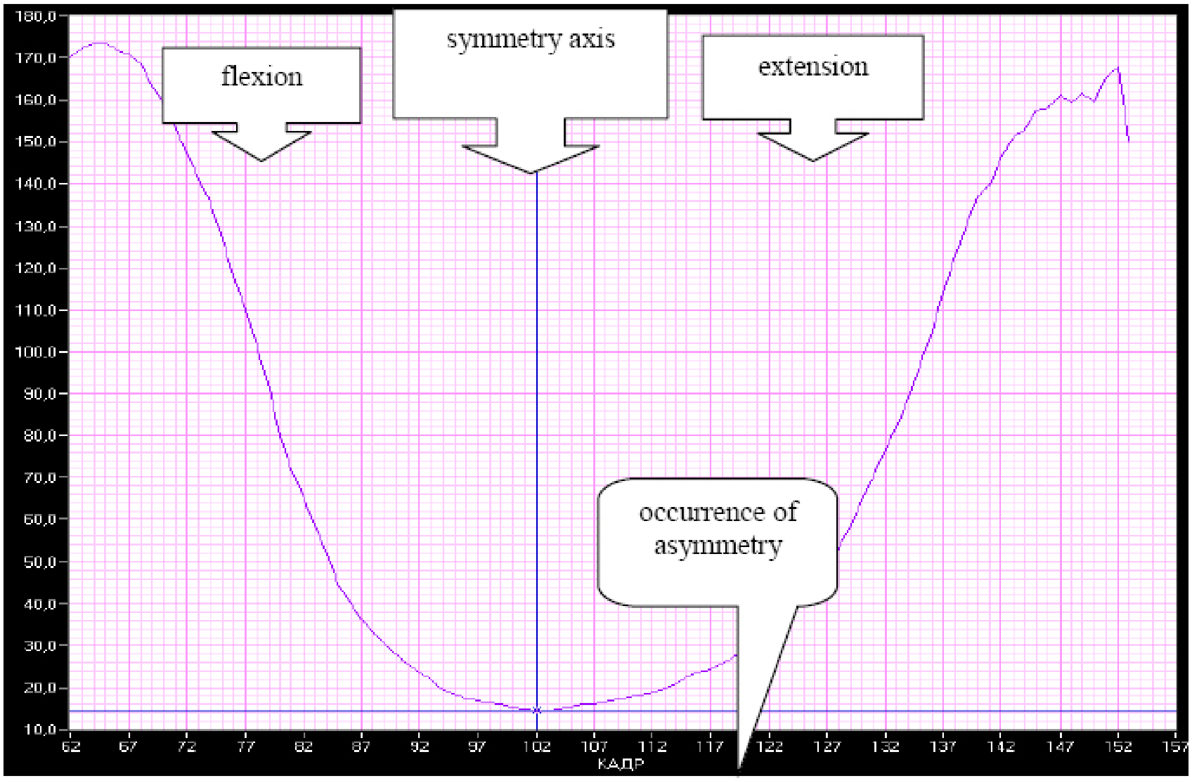

Figure 5. Occurrence of violation of the temporal order of angular movements during knee joint extension.

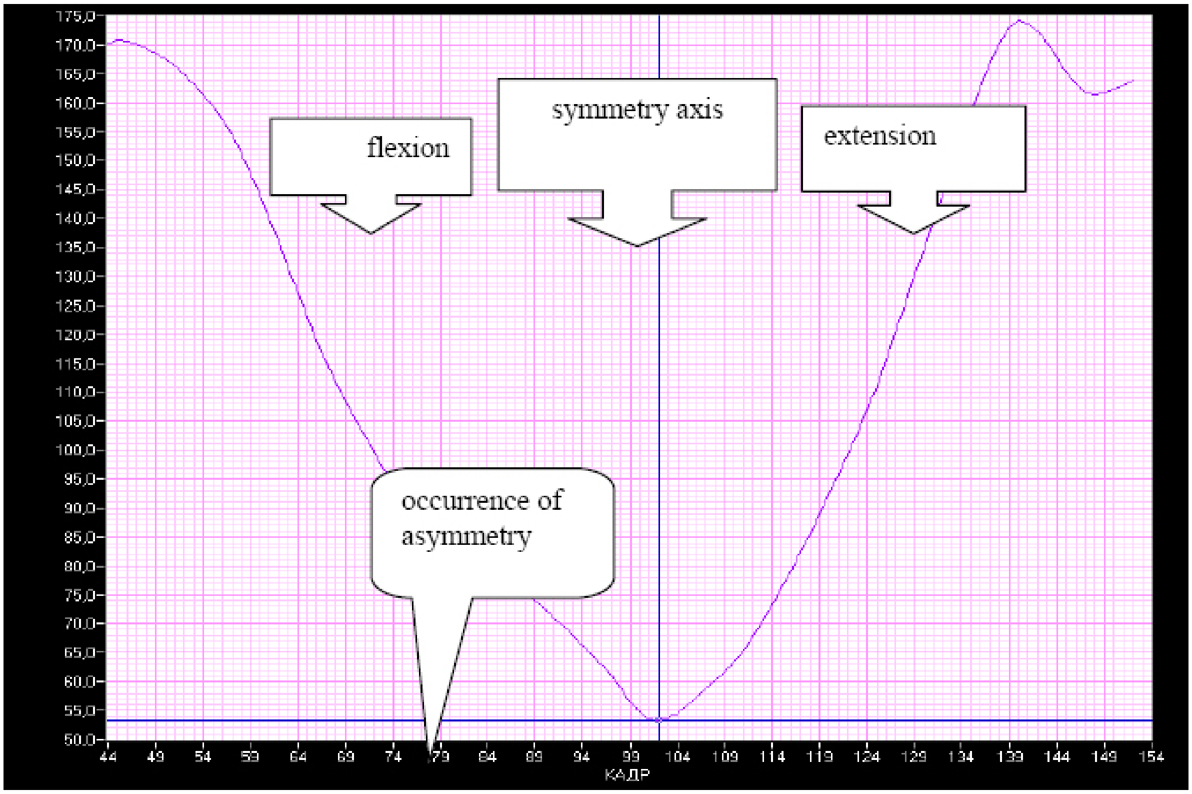

Figure 6. Occurrence of violation of the temporal order of angular movements during knee joint flexion

angular nee joint movement in the kinematic structure of squatting is formed by the age of six.

The quantity of children referred to the second group on the basis of occurrence of the dynamic symmetry of angular movements of ankle and hip joint does not change from the age of 5 to the age of 6. The reverse temporal order of angular movements in ankle and hip joint of children cannot be found. The reverse temporal sequence of the angular movements during joint extension to flexion found in case of all athletes is not characteristic of the kinematic structure of squats done by children of this age. However, occurrence of correction of angular movements during a series of squats makes it possible to conclude that forming of angular movements of squats would be developed in the later periods of ontogeny (Figure 7).

Thus, the study of occurrence of the dynamic symmetry of the spatiotemporal order of angular movements in ankle, knee and hip joint allows concluding that the general form of movement is formed by the age of six, which is characterized with:

- occurrence of the dynamic symmetry of the spatiotemporal order of angular movements in the knee joint, whereby the temporal order of angular movements during joint extension is a reverse temporal order of angular movements during joint flexion;
- occurrence of the dynamic asymmetry of spatiotemporal order of angular movements in hip and ankle joints;
- correction of angular movements during a series of squats towards formation of a dynamic symmetry of spatiotemporal order of angular movements;
- formation of dynamic symmetry of angular movements of spatiotemporal order in the kinematic structure in the ontogeny occurs in a heterotropic mode, which is evidenced by the time difference in forming dynamic asymmetry of the spatiotemporal order of angular movements in ankle, knee and hip joint during squat.

4. Discussion

In the course of the study, it was found that the spatiotemporal order of angular movements in ankle, knee and hip joints during squats occurs in the form of dynamic symmetry and dynamic asymmetry. Dynamic symmetry of angular movements represents a form of spatiotemporal order, whereby the spatiotemporal order of the angular movements during joint extension is a reverse temporal order of angular movements during joint flexion. The graphical trajectory characterizing occurrence of the dynamic symmetry of joint movement has a form of a

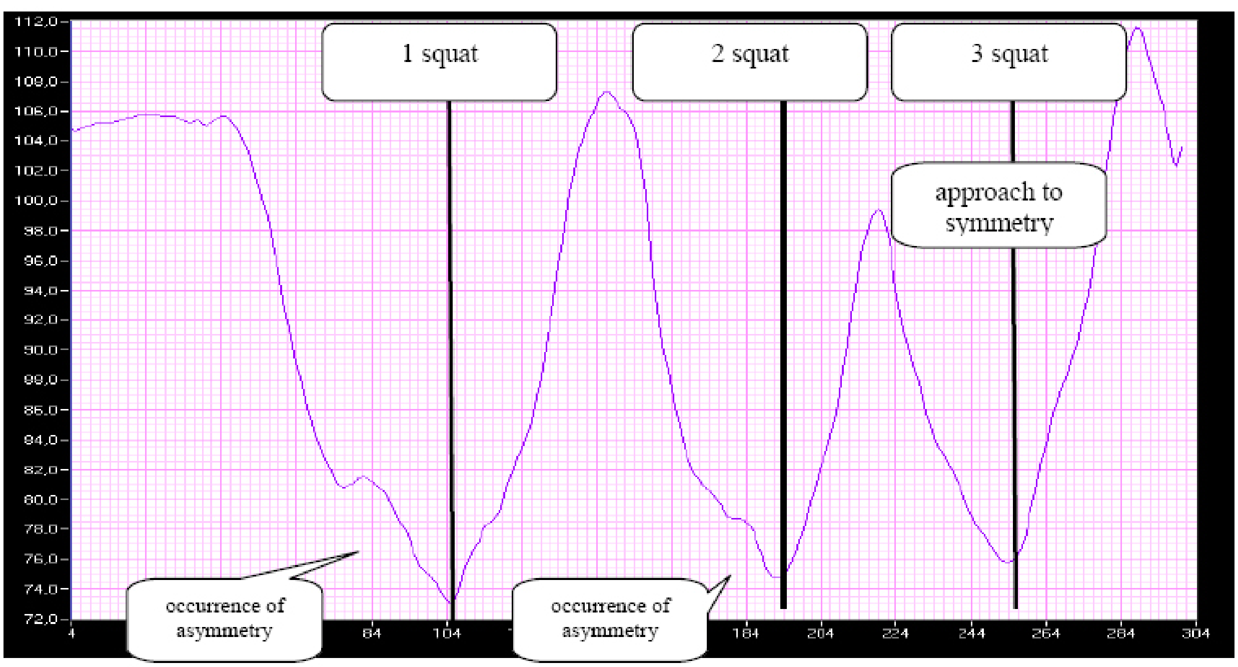

Figure 7 Change in the angular movements in ankle joint during squats done by 6-year old children (3 squats).

parabola. All other forms of the spatiotemporal order of angular movements represent occurrence of the dynamic asymmetry, which is expressed by variety of forms of graphic trajectories of joint movement.

Cross-transition of dynamic asymmetry into dynamic symmetry, and vice versa, is subject to change in the level of movement skill or conditions of its realization. At the stage of movement ability formation, during establishment of motor function in the ontogeny, when movements are controlled with an active role of thinking, the spatiotemporal order of angular movements occurs in the form of dynamic asymmetry. As far as motor action is perfected, the movement ability develops into the movement skill, and an active role of thinking in the movement regulation gives way to automation of regulatory mechanisms, which is characterized with reduction in the process of simulation of motional and spatial patterns. Under these circumstances, the dynamic asymmetry of spatiotemporal order of angular movements develops into the form of dynamic symmetry. Children demonstrate transition of the dynamic asymmetry into the dynamic symmetry in the course of motor function development in a heterotropic mode. The dynamic symmetry of the spatiotemporal order of angular movements in a knee joint during squats is formed in children of senior preschool age (5–6 years) and in case of ankle and hip joints – in the later periods of ontogeny.

The dynamic symmetry of spatiotemporal order of angular movements in knee, ankle and hip joints is characteristic of all Candidate Masters of Sports and Masters of Sports in powerlifting. Transition of dynamic symmetry into dynamic asymmetry of spatiotemporal order of angular movements occurs in case of more than 60% increase in the poundage. Dynamic asymmetry occurs simultaneously in all joints.

Thus, the dynamic symmetry and dynamic asymmetry are basic forms of spatiotemporal order of angular movements reflecting the degree of perfection and quality of realization of natural locomotions.

5. Conclusion

1. The spatiotemporal order of angular joint movements during squats occurs in the form of dynamic symmetry and dynamic asymmetry.
2. The dynamic symmetry of angular joint movement is characterized with the kinematic structure, whereby the spatiotemporal angular movement during joint extension is a reverse spatiotemporal angular movement during flexion. The graphical trajectory, which characterizes occurrence of dynamic symmetry of angular joint movement, has a form of a parabola.
3. Cross-transition of dynamic asymmetry into dynamic symmetry, and vice versa, is subject to change in the level of movement skill or conditions of its realization.
4. The dynamic asymmetry as a form of spatiotemporal order of angular joint movements prevails at the stage of the motor ability formation. Transition of motor ability into motor skill is characterized with change of the prevailing form of spatiotemporal order of angular movements from dynamic asymmetry into dynamic symmetry.
5. Children demonstrate transition of dynamic asymmetry into dynamic symmetry during squats in the course of motor function development in a heterotropic mode: first, dynamic symmetry of spatiotemporal order of angular movements is formed in the knee joint, then – in the ankle and hip joints.
6. Stability of occurrence of dynamic symmetry of angular joint movement during squats is observed in powerlifters up to overcoming of 60% poundage.
7. The dynamic symmetry of angular movements in joints of powerlifters is violated through change of the spatiotemporal order of joint extension. The spatiotemporal order of angular movement during flexion of joints of powerlifters remains stable in case of all applied kinds of poundage.

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