

Methodology for evaluating special fitness and competitive activity of highly skilled kayakers

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Abstract

Purpose: development of methodology for individual evaluating special fitness and competitive activity of highly skilled kayakers. **Material & Methods:** Participants. Fifty six athletes *were involved* in the tests (mean age 22.78 ± 2.57 years, body mass 84.82 ± 12.90 kg, body height 190.59 ± 7.79 cm; here and below mean *values* $\pm$ *standard deviation*, $M \pm s.d.$, are shown). All tested subjects were qualified rowing athletes, the participants and winners of the Ukrainian national and international competitions. **Methods.** The work included two experimental series. The first one was carried out on a rowing training machine “Concept-2” (USA). This simulator allows the rower to perform movements rather close to those in real rowing; detailed mechanographic characteristics of these movements can be recorded simultaneously. Recording of mechanograms of the movements and EMGs from the involved muscles was performed using a specialized complex “Noraxon’s 3D MyoMotion” (Noraxon Inc., USA). **Results:** The rationality of the rower’s movement structure is largely determined by the character of work and interaction of the posterior and anterior bundles of the deltoid muscle, which perform the rower’s arm movements during applying both “pulling” and “pushing” efforts. The following causes of individual rowing technique errors significantly affecting sports result were identified: general muscle rigidity, lack of sufficiently complete and timely muscle relaxation; untimely involvement of muscles in work (appearance of mutual activity zones of antagonist muscles); late start of muscle activity (inertial moments of movement of rower’s body biolinks are not provided before water entrapment); protracted, too long muscle activity (movement is performed entirely at the expense of muscular activity, without the use of inertial and propelling forces); low speed of muscle engagement in work leading, as a rule, to the “drop” of efforts on the oar. Two groups of athletes with diametrically opposite levels of physical capacity development and one group, which was characterized by their uniform development, were distinguished. **Conclusions:** All rowers are divided into two groups. The first group is characterized by rational coordination of movements at the beginning of the distance covering and pronounced disturbances in the work dynamics of the muscles of the body turn and the nature of effort applied to the oar at the end of the distance. In the second group, we encounter the opposite phenomenon: with an irrational movement structure at the beginning of the distance, there is a transition of work to a more correct character at the end of its covering.

Key words: kayakers, electromyography, testing, individualization.

Introduction

The significant density of high achievements of athletes who compete in international competitions is a characteristic feature of modern elite sports (Ackland et al., 2003; Diachenko et al., 2021). In most cyclic sports events, winners and medalists are separated by fractions of a second (Ieremenko et al., 2021). This situation is primarily due to the fact that the resources for sports improvement in the training of highly skilled athletes are exhausted to a great extent (Fedorchuk et al., 2020). Nowadays, the volume of training loads has increased almost to the maximum; the organizational aspects of designing different structural units of training, including individual sessions, micro- and macrocycles have been carefully worked out, the previously expressed differences in the equipment used have been eliminated (Carrasco et al., 2010). Experts in the theory and methodology of training in different countries are close to the understanding of the regularities of the formation of special fitness individual aspects and are unanimous in solving complex issues of planning optimization and management of sports training of highly skilled athletes (Nikonorov, 2015).

At present, the issue of developing fundamentally new approaches to improve the training system for international-class athletes seems to be extremely relevant (Diachenko et al., 2020; Kolumbet et al., 2020). The solution to this problem involves a creative rethinking of years of accumulated practical experience, scientific knowledge, and the search for untapped resources of sports achievements on this basis (Hill, 1993).

The best practice and a number of experimental studies convincingly show that a multifaceted and objective assessment of different body system functioning is necessary to optimize the process of sports

improvement management. The efficiency of the management process is largely determined by the presence of a complex of information attributes that reflect different aspects of athletes' fitness (Nakamura et al., 2004). The possibility of individualization of sports training process management is considered to be the decisive condition for optimization the functioning of different body systems and maximum effective use of athletes' motor potential. It is based on understanding the regularities of the formation of different aspects of sportsmanship (Fontes et al., 2002).

As of today, almost all leading experts note the priority importance of an individualized approach to the training of athletes. The individualized approach in sports implies taking into account the individuality of the athlete, i.e. typical individual anatomical, physiological, psychological features in the training process, the peculiarities of theoretical, technical, physical, tactical fitness, work and rest regimes, motivation for sports activities (Hagner-Derengowska et al., 2014). Individual approach contributes to the development of those qualities on which the success of sports activities depends, allows more full reveal of the abilities of athletes, more quickly achieve sports results and is most often used in the training of high-class athletes.

The use of an individual approach during planning methods, means, modes, and volumes of physical loads seems to be the most possible way of modeling with the usage of the athlete model characteristics. However, at present, model characteristics of special physical and technical fitness are mainly used in competitive activities (Waylung et al., 2019). Model characteristics reflecting functional, psychological fitness and morphological peculiarities of the model of the strongest athlete are insufficiently developed in most sports events. The increasing intensity of training loads in rowing indicates the need for individualized modeling based on the dynamics of the functional state in the process of long-term training (Fernandes et al., 2021).

One of the factors predetermining the final result of athletes' activity to a great extent is a perfect movement technique that is resistant to confounding impacts (Kolumbet et al., 2022; Mischenko et al., 2010). At the same time, due to the causality and interconnection of phenomena, the movements and actions of athletes are considered a sensitive indicator of the course of internal physiological processes of control and regulation, as a result of the integration of body systems (Mishchenko et al., 1995; Paquette et al., 2018).

A successful solution to the tasks of training process management is implausible without an in-depth study of the structure of athletes' movements, knowledge of the mechanisms of their construction, and ways to control them (Bourgois & Vrijens, 1998). This should be the basis for the development of effective means of motor improvement with account for the individual peculiarities of athletes (Zamparo et al., 1999.).

The study of individual peculiarities of kayakers' motor activity during covering the competitive distance is important for the successful training of highly skilled athletes (Pool et al., 2016). Methodological literature on kayaking and canoeing points out the complexity of movement coordination in this sports event (Jones et al., 2002; Shynkaruk et al., 2020). In addition, recommendations on the motor cycle and requirements for its execution are given (Coelho et al., 2021; Lopez-Plaza et al., 2019). To date, there are neither experimentally substantiated criteria for evaluating the level of technical mastery, nor data on the elements of a rational system of rowers' movements. The data on the interrelations of individual indices and elements of the system of movements in kayaking are next to none. The methodology of evaluating the structure of rowers' special fitness is a no less important aspect of the problem. Determination of criteria and identification of the individual predisposition of rowers to the preferential development of any of the physical qualities is very relevant (Lopez-Plaza et al., 2017). The assessment of special fitness is usually focused on such parameters as the time of covering the distance segment, pace and speed of the boat way, etc. (Morton & Billat, 2000). (Morton & Billat, 2000). This is the simplest assessment in practical work with athletes. Currently, this approach is no longer able to provide adequate management of the preparation of highly skilled rowers (Bishop et al., 2002). Issues related to the individual predisposition of rowers to the formation of the most important components of sportsmanship were practically not addressed in a rowing sport.

Studying the character of muscle work during rowing is not new in itself (Kolumbet et al., 2019). Various authors in different years have investigated the dynamics of applying efforts to the oar, speed of the boat way on the distance, heart rate, trunk rotation, and muscle activity during rowing (Borges et al., 2015; Kolumbet et al., 2022). However, none of the works on rowing known to us has a sufficiently obvious definition of the dependencies between all of the above parameters. Such an approach has two very significant drawbacks. Firstly, it does not provide valuable insights into the rowing technique in general and the mutual influence of its individual components. Secondly, the lack of detailed basic information to fully manage the process of technical training.

Purpose – to develop methodology for individual evaluating special fitness and competitive activity of highly skilled kayakers.

Material & Methods

Participants.

The study was carried out in the laboratory of the *State University of Trade and Economics* (Kyiv, Ukraine). *Fifty six* athletes were involved in the tests (*mean age* 22.78±2.57 years, *body mass* 84.82±12.90 kg, *body height* 190.59±7.79 cm; here and below mean values ± standard deviation, *M*±s.d., are shown). All tested

subjects were qualified rowing athletes, the participants and winners of the Ukrainian national and international competitions.

Methods.

The work included two experimental series. The first one was carried out on a rowing training machine “Concept-2” (USA) (Figure 1). This simulator allows the rower to perform movements rather close to those in real rowing; detailed mechanographic characteristics of these movements can be recorded simultaneously. Introduction of additional electrophysiological equipment enables the experimenter to record in a parallel manner the EMG activity from a wide range of the muscles. In the course of the tests on the simulator, the tested subject could visually track (on a special monitor) the rate of “rowing” (number of strokes per 1 min) and the power developed within each stroke (Kovalchuk et al., 2021).

Recording of mechanograms of the movements and EMGs from the involved muscles was performed using a specialized complex “Noraxon’s 3D MyoMotion” (Noraxon Inc., USA). Transducers sensitive to acceleration (accelerometers) were fixed on a number of limb and body links of the subject. Signals coming from these sensors and the software of the above complex allowed us to obtain ongoing values of the joint angles. Signals from mechanotransducers and EMG electrodes were digitized, transformed into radiosignals, and addressed to the recording device using a wireless system (Kovalchuk et al., 2021).



Figure 1. Realization of rowing test-movements on simulation sets

In a parallel manner, we recorded integral surface EMGs from the following right-limb muscles: m. brachioradialis, m. biceps brachii caput longum, mm. triceps brachii caput lateralis et longum, m. pectoralis major, mm. deltoideus pars scapularis et clavicularis, m. semitendinosus, m. latissimus dorsi, m. obliquus externus abdominis, m. gluteus maximus, m. rectus femoris, m. vastus medialis, m. biceps femoris, m. tibialis anterior, and m. gastrocnemius lateralis. Surface “*BiopacSystem EL 503*” electrodes (USA) were used. EMG signals were digitized and subjected to full-wave rectification and low-pass filtering (Kovalchuk et al., 2021).

“*OriginLab 8.5*” software was used for mathematical and statistical processing of the signals of mechanograms and EMGs recorded in the experimental series. To characterize the level of EMG activity, we measured integral values (areas) of the EMG discharges related to definite phases of the cycle. These values could be calculated for the entire rowing cycle (“stroke”) and separate parts of the latter. Values obtained for each separate stroke were subjected to statistical analysis. To estimate relations between different parameters, a procedure of calculation of linear regression was used. When the relations were nonlinear, nonlinear approximation was provided using a dose-response curve of “*OriginLab 8.5*” software (Kovalchuk et al., 2021).

Organization of study.

Researches were conducted in 2020-2021.

In the first stage (2020 year), the task of determining the optimal dynamics of the work of the athlete’s muscles was solved. This was necessary to achieve the best result and determine the connections between the rowing technique components (peculiarities of intermuscular coordination, trunk rotation, the dynamics of applying effort to the oar, and the speed of the boat way at a distance).

The task of the second stage (2021 year) was the development of a methodology for individual assessment of the special fitness of kayakers. This was necessary to identify the predisposition and determine the predominant development of the athlete’s physical qualities.

Statistical analysis. During experimental data processing, we determined the average values of indices and their errors ($M \pm m$), the degree of difference of averages and the significance of differences (t , p) (Byshevets et al., 2019).

The study was conducted in compliance with the ethical principles of the European Convention and the Helsinki Declaration (ethics principles regarding human experimentation). It was confirmed by the Bioethics Commission of the University. Examined provided written approvals for analysis and subsequent disclosure.

Results & Discussion

Compared to previous studies that addressed investigation of kayaking technique, we have introduced a new fundamental level in the study of the coordination structure of movements - the level of intermuscular coordination.

The first stage (2020 year): the study of the coordination of movements during rowing and the management of the process of technical training of kayakers.

Obtained results allow singling out a number of intermuscular coordination peculiarities, which determine the rationality of rowing technique. First of all, the clearly expressed phases of muscle tension and relaxation should be noted, which are involved in the execution of this or that element of the movement. The results of our studies do not allow us to agree with the conclusions of Hartmann & Mader (1993), Papandreou et al. (2020) that the same rower's muscles work both during draw stroke from the same and the other side. On the contrary, we observed an alternating activity of these muscles with a clear differentiation of those performing "pulling" and "pushing" efforts during rowing to different sides. The duration of muscles' bioelectrical silence in skilled rowers exceeds the time of their activity by more than two times. We consider this fact as a twofold advantage. In the first place, pulse mode of muscle work with long period of their relaxation leads to economy of the rower's body energy resources during distance covering. In the second place, the pulse mode of muscle work with long period of muscle relaxation allows performing ballistic movement, where the beginning of movement of body biological links is executed by short and powerful muscle contractions and continues at the expense of inertial and reactive forces, which appear as a result of the movement (Michael et al., 2008).

One of the main features of the motion rational structure is that prerequisites for a successful stroke are created at the end of the previous stroke and during an airborne phase of the rowing cycle. The airborne phase of the cycle should be considered as an active phase of movement in connection with the preventive activity in the phase of pulling the muscles involved in rowing but not due to the fact that there can be residual muscle activity (Sheyhlouvand et al., 2018). Throughout the competitive distance, the muscles that perform "pulling" (the latissimus dorsi, teres major, posterior bundles of the deltoid muscle) and "pushing" (pectoralis major muscle, anterior bundles of the deltoid muscle) efforts, as well as those that rotate the body (external oblique abdominal muscles) are involved in the work (until the catch).

There is an opinion (Guevara-Perez, 2022) that preventive activity of oblique abdominal muscles before a catch leads to lateral trunk vibrations and the boat itself, which is irrational. The results of our studies allow us to claim that it is just the preventive activity of these muscles that plays a determining role in successful rowing. Early onset of oblique abdominal muscles activity provides a moment of inertia of trunk turn before the catch, which allows using the mass of the athlete's body to the maximum during a stroke.

The rationality of the rower's movement structure is largely determined by the nature of work and interaction between the posterior and anterior deltoid muscle bundles, which perform the rower's arm movements while applying both "pulling" and "pushing" efforts.

Data on the character of work and interactions of external oblique abdominal muscles, anterior and posterior deltoid muscle bundles and the role of the work of these muscles in the dynamics of trunk turn, the nature of efforts applied to the oar and boat speed at a distance were used to form a rational structure of movements in the process of athletes' training.

Consideration of the rower's movement structure (starting from muscle work character and up to a speed of boat way) allowed determining the cause-effect relationship between these components of rowing technique and identifying the causes of individual rowing technique errors, which significantly affect sports result.

Among these errors, the following should be noted:

- 1) general muscle stiffness, lack of sufficiently complete and timely relaxation;
- 2) untimely involvement of muscles in work (appearance of zones of mutual activity of antagonist muscles);
- 3) late onset of muscle activity (inertial moments of movement of the rower's body biolinks are not provided before the catch);
- 4) protracted, too long muscle activity (the movement is performed completely at the expense of muscle activity, without using inertial and reactive forces);
- 5) low speed of muscle engagement in work, leading, as a rule, to the "drop" in the efforts on the oar.

Correction of the above errors was based on subordinating the rower's movement structure to general regularities of biomechanical systems with the preservation of individual peculiarities of the rowing technique.

The presence of errors in the structure of movements of highly skilled athletes is strictly individual, both in terms of their existence in general, and their manifestation in the course of covering the competitive distance. It was found, in particular, that one group of athletes was characterized by the absence of errors at the beginning of the distance and pronounced violations in the movement structure at the end of it, whereas in the other group, on the contrary, an irrational movement structure and errors in technique were observed at the beginning of the distance, while in the finishing segment the errors became less expressed or almost disappeared. The third group of athletes was characterized by the presence of errors in movement technique throughout the entire distance

with some variation relative to the average characteristics of violations occurring in the structure of movements throughout the entire distance.

The foregoing can be illustrated by several examples reflecting the dynamics of the manifestation of errors. Athlete O.S-v. (Figure 2) has a noticeable tendency in the shift of the moments of the beginning of the bioelectrical activity of the external oblique abdominal muscles to the moment of effort on the oar in both strokes when finishing at a distance of 500 m. In addition, very low values are noted in the right stroke amplitudes of fluctuations of biopotentials of the external oblique abdominal muscle at the moment of the catch. The consequence of this is the beginning of the trunk turn after the catch in the left and at the moment of the catch in the right strokes. In the left stroke, the failure of the effort on the oar increases significantly.

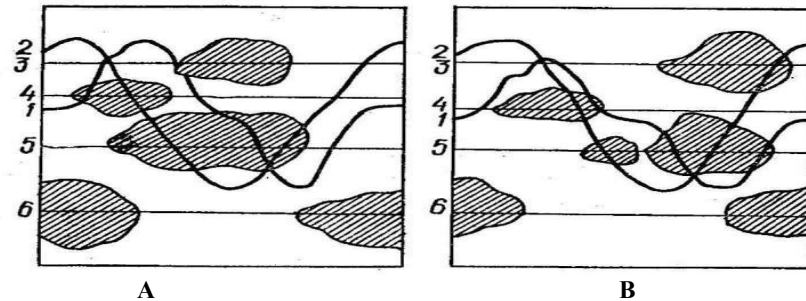


Figure 2. Dynamics of effort application to the oar, trunk rotation, and muscle electrical activity, recorded in athlete O. S-v during covering a 500 m distance

Legend: **A** - 50-150 m segment of distance; **B** - 400-500 m segment of distance; 1 - dynamics of force application to the oar; 2 - trunk rotation goniogram; 3-5 - electromyograms of left and right oblique abdominal muscles, posterior and anterior bundles of the deltoid muscle

A pronounced improvement in the structure of movements is observed in athlete A.P-v (Figure 3) by the finish of the 500 m distance. Both trunk rotation dynamics and character of effort application to the oar improve. These positive changes are caused by an increased period of preliminary activity of external oblique abdominal muscles and improved interaction of anterior and posterior bundles of the deltoid muscle.

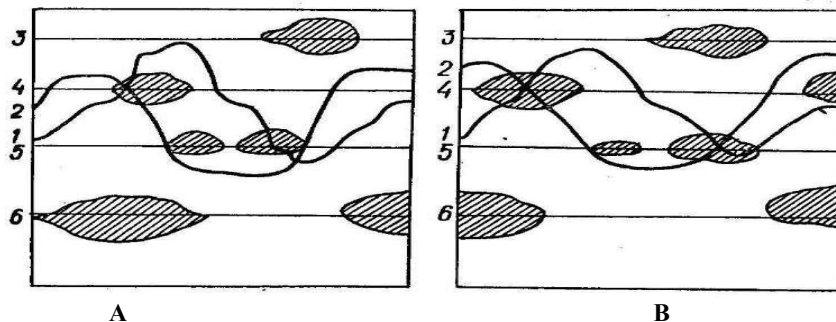


Figure 3. Dynamics of effort application to the oar, trunk rotation, and muscle electrical activity, recorded in athlete A. P-v during covering 500 m distance

Legend: **A** - 50-150 m segment of distance; **B** - 400-500 m segment of distance; 1 - dynamics of force application to the oar; 2 - trunk rotation goniogram; 3-5 - electromyograms of left and right oblique abdominal muscles, posterior and anterior bundles of the deltoid muscle

Our studies allowed to single out the most generalized properties of the system of movements for various cyclic sports events, which significantly affect the efficiency of athletes' motor actions at different segments of the competitive distance.

The findings indicate that the main attention in assessing the technique of sports movements should be paid to the processes of compensatory-adaptive nature occurring in the structure of athletes' movements during competitive activity. Focusing on the elimination of destabilizing changes in the structure of motor activity alone does not have a significant positive effect in the training of highly skilled athletes (Withers et al., 1993).

The second stage (2021 year): determining the structure of special fitness and managing the training process of kayakers.

One of the tasks of our studies was to develop a methodology for individual assessment of rowers' special fitness to reveal predisposition and preferential development of certain physical qualities. When interpreting the obtained data, we proceeded from the fact that the value of functional shifts in the body during a certain load

execution characterizes the intensity of activity of individual organs, systems, and the rower's body in general, as well as the energy cost of such work (Mischenko et al., 2010; Yang et al., 2017).

The values of functional shifts in a rower's body characterize: speed and intensity of oxygen consumption, oxygen debt and demand for a given work, maximum and average heart rate. The economy of work can be judged by the data on energy cost and power of the work performed (which is recognized as the most informative criterion), assessment of special work capacity. Such characteristics as ventilation equivalent, oxygen effects of respiratory and cardiac cycles reflect the economy of activity of the rower's body functional systems. The efficiency of using the efforts developed by the athlete is evaluated by correlating the resultant indices of the rower's work activity with the power of work, as well as by the characteristics that reflect the quality of the application of efforts in the stroke, stroke length, ratio of expended and useful efforts, the coefficient of the body mass use in a rowing cycle.

In evaluating the kinematic and biodynamic characteristics of the rowing cycle, we proceeded from the fact that the most characteristic feature is a high dynamic resistance to the confounding effect of fatigue or compensatory rearrangement of the main components of the movement in better prepared rowers.

Analysis of the results of the study permitted to identify two groups with diametrically opposite levels of development of physical qualities and one group of athletes, which was characterized by their uniform development.

The first group was distinguished by high indices of power and economy of work performed during covering a competitive distance. Such rowers (which we referred to as athletes with preferential development of speed-strength qualities) demonstrated better sports results on short distances (Table 1).

Table 1. Special fitness characteristics of the first group of highly skilled kayakers (n=18)

Characteristics	Rowers with preferential development of speed-strength qualities		
	50-100 m	200-300 m	400-500 m
Way of the boat distance speed, m.s. ⁻¹	4.02±0.40	3.94±0.36	3.87±0.34
Mean pulse rate, bt.min. ⁻¹	173.4±10.9	185.6±7.1	190.2±5.4
An average impulse of force over two strokes, kg.s	8.59±1.26	7.57±1.55	7.09±1.09
Power of work performed in a rowing cycle, kgm.s ⁻¹	64.5±19.1	53.8±16.4	48.7±13.2
Stroke power of work, kgm.s ⁻¹	85.3±19.1	71.5±16.4	65.1±13.2
Rowing pace, st.min. ⁻¹	97.1±12.5	93.9±11.2	92.9±9.0
Rowing rhythm, c.u.	75.6±3.8	75.5±4.0	75.3±4.0
The difference in force impulses between strokes from different sides of the boat, kg.s	2.26±0.92	1.89±1.07	1.21±1.27
The difference in the time of effort maintaining during strokes from different sides of the boat,%	6.0±3.4	7.9±5.6	8.2±5.9
The difference between the values of maximum effort during strokes from different sides of the boat, kg	6.06±3.41	3.94±3.21	2.89±1.61

The second group was distinguished by high efficiency of effort application, symmetry of movements, and successful performance at long competitive distances. Such rowers were classified as athletes with predominant development of special endurance (Table 2).

Table 2. Special fitness characteristics of the second group of highly skilled kayakers (n=17)

Characteristics	Rowers with preferential development of endurance		
	50-100 m	200-300 m	400-500 m
Way of the boat distance speed, m.s. ⁻¹	3.89±0.23	3.91±0.25	3.93±0.28
Mean pulse rate, bt.min. ⁻¹	174.7±4.5	185.5±6.4	188.3±8.2
Average impulse of force over two strokes, kg.s	5.66±0.74	5.42±0.84	5.19±0.86
Power of work performed in a rowing cycle, kgm.s ⁻¹	40.7±6.9	37.3±6.8	36.2±6.9
Stroke power of work, kgm.s ⁻¹	54.1±9.3	49.5±9.8	47.2±9.5
Rowing pace, st.min. ⁻¹	95.8±5.03	93.3±5.3	94.1±5.2
Rowing rhythm, c.u.	75.1±3.0	75.3±2.5	76.9±2.5
The difference in force impulses between strokes from different sides of the boat, kg.s	0.61±0.43	0.87±0.57	0.77±0.37
The difference in the time of effort maintaining during strokes from different sides of the boat,%	7.37±8.73	8.38±8.31	10.31±8.71
The difference between the values of maximum effort during strokes from different sides of the boat, kg	1.65±1.17	2.18±1.74	2.00±3.31

Rowers of the third group differed in the average values of the above mentioned indices and had the same success in both short and long competitive distances (Table 3).

Table 3. Special fitness characteristics of the third group of highly skilled kayakers (n=21)

Characteristics	Rowers with uniform development of physical qualities		
	50-100 m	200-300 m	400-500 m
Way of the boat distance speed, m.s. ⁻¹	3.84±0.24	3.79±0.19	3.73±0.19
Mean pulse rate, bt.min. ⁻¹	175.9±7.6	185.6±7.4	189.5±6.1
Average impulse of force over two strokes, kg.s	7.13±1.14	7.17±1.20	7.24±1.11
Power of work performed in a rowing cycle, kgm.s ⁻¹	47.6±8.5	45.5±6.1	46.7±4.8
Stroke power of work, kgm.s ⁻¹	64.2±9.5	59.4±7.7	60.8±5.9
Rowing pace, st.min. ⁻¹	92.5±10.3	89.9±9.0	93.2±10.3
Rowing rhythm, c.u.	76.0±3.8	76.6±2.5	76.8±2.3
The difference in force impulses between strokes from different sides of the boat, kg.s	2.05±1.57	2.28±1.70	2.45±1.60
The difference in the time of effort maintaining during strokes from different sides of the boat, %	7.18±5.80	8.29±7.21	6.92±5.40
The difference between the values of maximum effort during strokes from different sides of the boat, kg	5.33±2.90	5.31±2.40	5.71±2.10

Let's consider the peculiarities of covering the competitive distance by highly skilled rowers: 1) with predominant development of speed-strength qualities; 2) with significant development of special endurance; 3) with equal development of speed-strength qualities and special endurance. Rowers of the first group are characterized by higher values of indices, which reflect the power and economy of the work performed. Athletes of the second group have significantly higher values of efficiency of effort application and symmetry of movements. The average level of all these indices of special fitness is observed in the third group of rowers.

Athletes with preferential development of speed-strength qualities and those with predominant development of special endurance have no significant difference in speed of covering 500 m distance and pulse rate. However, there are significant differences in other indices of special fitness (Table 4).

Rowers with even development of physical qualities have differences in all recorded indices as compared to those of the first two groups. Irrespective of the individual predisposition of rowers to the development of this or that quality, a decrease in the speed of boat way as it drew on distance was noted in all athletes. The lowest speed of the boat way on the distance of 500 m was observed at the segment of 250-375m from the start. Rowers with a predominant development of special endurance tend to cover the distance more evenly and with a less pronounced decrease in the speed of the boat way. The dynamics of the speed of the boat way during covering a 500 m distance is directly associated with the processes of lactate accumulation in the rower's muscles and peculiarities of rearrangement of movement structure during performance of work and fatigue development.

The results of studies in which the covering of a 500 m distance was modeled allow stating the occurrence of a certain critical state in the rower's body approximately by the middle of the distance. A maximum lactic acid concentration in the muscles, the highest decrease in the power of the work performed, and subsequently the speed of the boat way are observed. In addition, the very poor compensation for the decreasing power of work should be mentioned. Only in a segment of 200-300 m from the start of the distance a decrease in the speed of the boat way, which is inadequate to the amount of power developed by the athlete, is observed along with an improvement in the symmetry of movements. More significant rearrangements in the coordination of movements were revealed in athletes with predominant development of special endurance, for whom a significant decrease of efficiency of efforts applied and simultaneous increase of asymmetry of extremity movements were typical.

Table 4. Differences in indices of special fitness structure of kayakers with preferential development of speed-strength (A), special endurance (B), and equal development of qualities (C) while covering 500 m distance at a maximum speed

Indices	Differences between groups of rowers		
	A-B	A-C	B-C
Way of the boat speed	=	+	+
Mean pulse rate	=	=	=
Impulse of force	+	+	+
Maximum effort on the oar	+	=	+
Average effort on the oar	+	+	+
Amount of work in rowing cycle	+	+	+
The power developed by the rower in the rowing cycle	+	+	+
The power developed by the rower in the stroke	+	+	+
Efficiency coefficient of effort application to the oar	=	+	=
Time of effort increase on the oar	=	=	=
Time of maintaining effort on the oar	=	=	=
Stroke length	=	+	=
Rowing pace	=	=	=
Rowing rhythm	=	=	=
The difference in force impulses between strokes from different sides of the boat	+	=	+

The difference in time of effort increase on the oar between strokes from different sides of the boat	=	=	=
The difference in the time of effort maintaining on the oar during strokes from different sides of the boat	=	=	=
The difference between the values of maximum effort during strokes from different sides of the boat	+	=	+

Explanation of symbols: + → P<0.05 = → P>0.05

Several segments of the distance should be noted, the efficiency of covering which is associated with qualitative changes in the coordination of movements of athletes. Most often these are sections 200-250 m and 400-450 m from the start.

Table 5. Due values of special fitness of kayakers with preferential development of speed-strength qualities

Characteristics	100 m at	500 m distance		
	maximum pace	50-150 m	200-300 m	400-500 m
Boat speed on the segment, m.s ⁻¹	4.44-4.77	3.82-4.22	3.76-4.12	3.69-4.04
An average impulse of force over two strokes, kg.s	8.19-8.71	7.96-9.21	6.80-8.35	6.50-7.70
Power of work performed in a rowing cycle, kgm.s ⁻¹	75.5-82.5	55.0-74.1	45.6-62.9	42.1-55.2
Stroke power of work, kgm.s ⁻¹	95.6-106.6	72.9-97.8	60.2-82.8	55.5-74.5
The difference in force impulses between strokes from different sides of the boat, kg.s	2.44-3.11	-	1.36-2.44	0.90-1.64
The difference in the time of effort maintaining during strokes from different sides of the boat, %	8.03-18.10	-	-	-
The difference between maximum efforts during strokes from different sides of the boat, kg	6.71-10.61	-	-	-

Highly skilled athletes are distinguished by more qualitative rearrangements of the movement structure as they cover the competitive distance. Athletes with predominant development of speed-strength qualities are characterized by a sharp decrease in power by the end of the 200-meter distance, and retention of the speed of the boat way at the expense of increased efficiency of effort application to the oar. When passing the 400 m mark, they significantly improve the symmetry of movements, which is a compensatory mechanism during the exhaustion of opportunities to improve the efficiency of effort application.

Analysis of questionnaire details and training diaries of athletes did not show significant differences in the training system of the examined rowers.

A statistical framework, which determined the belonging of athletes to this or that group, was formed as a result of preliminary studies. The training process of kayakers was managed based on this division of athletes into groups.

Assessment of the special fitness of rowers was based on determining the belonging of the examined athlete to one of the groups. The rower's examination data were compared with the due values for each group (Tables 5-6).

The athlete was then assigned to the group which range of due values included most of his individual characteristics.

Table 6. Due values of special fitness of kayakers with preferential development of endurance

Characteristics	100 m at	500 m distance		
	maximum pace	50-150 m	200-300 m	400-500 m
Boat speed on the segment, m.s ⁻¹	4.45-4.61	3.77-4.01	3.78-4.04	3.78-4.08
An average impulse of force over two strokes, kg.s	4.88-5.28	5.28-6.04	4.98-5.85	4.75-5.64
Power of work performed in a rowing cycle, kgm.s ⁻¹	47.8-53.8	37.1-44.3	33.8-40.8	32.7-39.8
Stroke power of work, kgm.s ⁻¹	61.1-69.1	49.3-58.9	44.5-54.6	42.3-52.1
The difference in force impulses between strokes from different sides of the boat, kg.s	0.54-0.79	-	0.51-1.06	0.58-0.96
The difference in the time of effort maintaining during strokes from different sides of the boat, %	2.09-4.16	-	-	-
The difference between maximum efforts during strokes from different sides of the boat, kg	1.44-2.21	-	-	-

Such a division became the starting point for further planning of athletes' training (training process structure, ratio of volumes and intensity of loads of different preferential directions, etc.). The ranking of athletes according to the level of special fitness was made within each of the three identified groups.

Conclusions

1. Individual peculiarities of rowers' movement coordination during covering a competitive distance of 500 m were determined.
2. All rowers are divided into two groups. The first group is characterized by rational coordination of movements at the beginning of the distance and expressed violations in the dynamics of the trunk-turn muscles and the character of effort application to the oar at the end of the distance. In the second group, we observe the opposite phenomenon: with an irrational structure of movements at the beginning of the distance, there is a transition of work to a more correct character at the end of its covering.
3. The most preferable option to increase the efficiency of technical training of athletes is to use the method of designing generalized and individual models of motor action structure.
4. Preparation of rowers with account for their predisposition to the formation of the most important components of sportsmanship represents the most preferable option.
5. When drawing up individual plans of athletes' preparation, the coaches should take into account these practical recommendations and adhere to the recommended directions of training.
6. Repeated examinations (four months later) revealed the effectiveness of managing the process of technical training of kayakers based on intermuscular coordination correction.

Conflict of interest

The authors declare that there is no conflict of interests.

References

- Ackland, T.R., Ong, K.B., Kerr, D.A., & Ridge, B.R. (2003). Morphological characteristics of Olympic sprint canoe and kayak paddlers. *Journal of Science and Medicine in Sport*, 3, 285–294.
- Bishop, D., Bonetti, D., & Dawson, B. (2002). The influence of pacing strategy on VO_2 and supra-maximal kayak performance. *Medicine & Science in Sports & Exercise*, 34(6), 1041–1047.
- Borges, T.O., Dascombe, B., Bullock, N., & Coutts, A.J. (2015). Physiological characteristics of well-trained junior sprint kayak athletes. *International Journal of Sports Physiology and Performance*, 10, 5, 593–539. <http://doi.org/10.1123/ijsp.2014-0292>.
- Bourgois, J., & Vrijens, J. (1998). Metabolic and cardiorespiratory responses in young oarsmen during prolonged exercise tests on a Kayak ergometer at power outputs corresponding to two concepts of anaerobic threshold. *European Journal of Applied Physiology and Occupational Physiology*, 77, 1/2, 164–169.
- Byshevs, N., Shynkaruk, O., Stepanenko, O., et al. (2019). Development skills implementation of analysis of variance at sport-pedagogical and biomedical researches. *Journal of Physical Education and Sport*, 19, 6, 2086–2090. <http://doi.org/10.7752/jpes.2019.s6311>.
- Byshevs, N., Denysova, L., Shynkaruk, O., et al. (2019). Using the methods of mathematical statistics in sports and educational research. *Journal of Physical Education and Sport*, 19, 3, 1030–1034. <http://doi.org/10.7752/jpes.2019.s3148>.
- Carrasco, P.L., Martinez, D.C.I., De Hoyo, L.M., Sanudo, C.B., & Ochiana, N. (2010). Reliability and validity of a discontinuous graded exercise test on Dansprint[R] ergometer. *Ovidius University Annals, Series Physical Education and Sport/Science, Movement and Health*, 10(2), 148.
- Coelho, A.B., et al. (2021). Prediction of simulated 1,000 m kayak ergometer performance in young athletes. *Frontiers in Public Health*, 8, 526477. <http://doi.org/10.3389/fpubh.2020.526477>.
- Diachenko, A., Shkrebtii, Iu., & Jia Guo. (2020). Specific characteristics of special work capacity functional provision in kayakers and canoeists. *Theory and Methods of Physical Education and Sports*, 2, 42–46. <http://doi.org/10.32652/tmfvs.2020.2.42-46>
- Diachenko, A., Rusanova, O., Guo Pengcheng, Kong Xianglin, Huang Zijian, & Guo Jia. (2021). Characteristics of the special physical fitness of paddlers at a distance of 200 m. *Teoriã ta Metodika Fizičnogo Vihovannã*, 21, 1, 43–49. <https://doi.org/10.17309/tmfv.2021.1.06>.
- Diachenko, A., Rusanova, O., Huang Zijian, Gao Xueyan, Guo Jia, & Chenqing Ye. (2021). Functional and physical capacity indicators of kayakers racing 1000, 500, and 200 m distances: a randomized study. *Journal of Physical Education and Sport*, 21, 3, 1325–1330. <http://doi.org/10.7752/jpes.2021.03168>
- Fedorchuk, S., Kravchenko, V., Fibakh, K., Lysenko, O., & Shynkaruk, O. (2021). State of neurodynamic functions and dynamic muscular endurance of skilled rowers. *Sports Medicine, Physical Therapy & Occupational Therapy*, 1, 128–133. <http://doi.org/10.32652/spmed.2021.1.128-133>.
- Fernandes, R.A., López-Plaza, D., Correias-Gómez, L., Gomes, B.B., & Alacid, F. (2021). The importance of biological maturation and years of practice in kayaking performance. *International Journal of Environmental Research and Public Health*, 18, 16, 8322. <http://doi.org/10.3390/ijerph18168322>.
- Fontes, E.B., Borges, T.O., Altimari, L.R., Melo, J.C., Okano, A.H., & Cyrino, E.S. (2002). Influência do número de coordenadas e da seleção de distâncias na determinação da velocidade crítica na canoagem de velocidade. *Revista Brasileira de Ciência a Movimento*, 10, 161.

- Guevara-Pérez, Juan Carlos et al. (2022). Raiders of the Olympic Values: Perception of the development of Women's canoeing in Spain for Tokyo 2021. *International Journal of Environmental Research and Public Health*, 19, 11, 6909. <http://doi.org/10.3390/ijerph19116909>.
- Hagner-Derengowska, M., Hagner, W., & Zubrzycki, I., et al. (2014). Body structure and composition of canoeists and kayakers: Analysis of junior and teenage Polish national canoeing team. *Biology of Sport*, 31, 4, 323-326. <http://doi.org/10.5604/20831862.1133937>.
- Hartmann, U., & Mader, A. (1993). Modeling metabolic conditions in Kayak through post-exercise simulation. *FISA coach*, 4, 4, 1-15.
- Hill, D.W. (1993). The critical power concept: a review. *Sport Medicine*, 16(4), 237-254.
- Ieremenko, N., Shynkaruk, O., Moseychuk, Yu., et al. (2021). Analysis of main ergometric parameters of elite kayak athletes specialized in different distance events. *Sport Mont*, 19, 2, 3-7. <http://doi.org/10.26773/smj.210610>.
- Jones, M., Wilkerson, D.P., Vanhatalo, A., & Burnley, M. (2002). Influence of pacing strategy on O₂ uptake and exercise tolerance. *Scandinavian Journal of Medicine & Science in Sports*, 18(5), 615-626.
- Kolumbet, A.N., Dudorova, L.Y., Dovgych, A.A., Ivaschenko, E.A., Melnik, A.A., Nichiporenko, I.V., & Suprunenko, M.V. (2019). Improvement of cyclist pedaling technique by studying their individual differences. *Journal of Physical Education & Sport*, 19(3), 229, 1577-1584. <https://doi.org/10.7752/jpes.2019.03229>.
- Kolumbet, A.N., Maximovich, N.Y., Korop, M.Y., Gamov, V.G., & Bakanychev, O.V.. (2022). Peculiarities of cyclists' respiratory adaptation to strenuous muscular activity in different training periods. *Journal of Physical Education and Sport*, 22 (3), 92, 732-740. <http://doi.org/10.7752>.
- Kolumbet, A.N., Babyna, N.A., Natroshvili S.G., Maximovich, N.Y., & Korop M.Y. (2022). Express control of aerobic and anaerobic metabolism of athletes in cyclic sports events. *Journal of Physical Education and Sport*, 22(5), 149, 1190-1196. <http://doi.org/10.7752/jpes.2022.05149>.
- Kovalchuk, V., Mospan, M., Smoliar, I., Adyrkhaeva, L., Kolumbet, A. (2021). Optimazation of the process of technical fitness management of highly skilled swimmers. *Journal of Physical Education and Sport*, 21(5), 337, 2507-2514. <http://doi.org/10.7752/jpes.2021.051337>.
- López-Plaza, D., Alacid, F., Muyor, J.M., & López-Miñarro, P.Á. (2017). Sprint kayaking and canoeing performance prediction based on the relationship between maturity status, anthropometry and physical fitness in young elite paddlers. *Journal of Sports Sciences*, 35, 11, 1083-1090. <http://doi.org/10.1080/02640414.2016.1210817>.
- López-Plaza, D., et al. (2019). Morphological and physical fitness profile of young female sprint kayakers. *Journal of Strength and Conditioning Research*, 33, 7, 1963-1970. <http://doi.org/10.1519/JSC.0000000000002511>
- Michael, J.S., Rooney, K.B., & Smith, R. (2008). The Metabolic demands of kayaking: a review. *Journal of Sports Science & Medicine*, 7(1), 1-7.
- Mischenko, V.S., & Monogarov, V.D. (1995). Phisiology del deportista. Editorial Paidotribo.
- Mishchenko, V., Suchanowski, O., Shynkaruk, O., et al. (2010). Individualities of cardiorespiratory responsiveness to shifts in respiratory homeostasis and physical exercise in homogeneous groups of high performance athletes. *Baltic Journal of Health and Physical Activity*, 1, 13-29.
- Mishchenko, V.S., & Suchanowski, A. (2010). Athlete's endurance and fatigue characteristics related to adaptability of specific cardiorespiratory reactivity. Gdansk, AWFIS.
- Morton, R.H., & Billat, V. (2000). Maximal endurance time at VO₂max. *Medicine & Science in Sports & Exercise*, 32, 1496-504.
- Nakamura, F.Y., Borges, T.O., Sales, O.R., Cyrino, E.S., & Kokubun, E. (2004). Estimativa del costo energético y contribución de las diferentes vias metabólicas en el canotage de velocidad. *Revista Brasileira de Medicina do Esporte*, 10(2), 17-29.
- Nikonorov, A. (2015). Power development in sprint canoeing. In: Isorna Folgar M, et al. Training Sprint Canoe. *Editora*, 169-183.
- Papandreou, A., Philippou, A., Zacharogiannis, E., & Maridaki, M. (2020). Physiological adaptations to high-intensity interval and continuous training in kayak athletes. *Journal of Strength and Conditioning Research*, 34, 8, 2258-2266. <http://doi.org/10.1519/JSC.0000000000002710>.
- Paquette, M., Bieuzen, F., & Billaut, F. (2018). Muscle oxygenation rather than VO₂max as a strong predictor of performance in sprint canoe-kayak. *International Journal of Sports Physiology and Performance*, 1-9. <http://doi.org/10.1123/ijssp.2018-0077>.
- Pool, D.C., Burnley, M., Vanhatalo, A., Rossiter, H.B., & Jones, A.M. (2016). Critical power: an important fatigue threshold in exercise physiology. *Medicine & Science in Sports & Exercise*, 48(11), 2320-34.
- Rosdahl, H.G., & Gullstrand, L. (2009). Evaluation of the Oxycon Mobile metabolic system against the Douglas bag method. *European Journal of Applied Physiology*, 109(2), 159-171.
- Sheykhlouvand, M., Khalili, E., Gharaat, M., Arazi, H., Khalafi, M., & Tarverdizadeh, B. (2018). Practical model of low-volume paddling-based sprint interval training improves aerobic and anaerobic performances in

- professional female canoe polo athletes. *Journal of Strength and Conditioning Research*, 32, 8, 2375-2382. <http://doi.org/10.1519/JSC.0000000000002152>.
- Shynkaruk, O., & Taibolina, L. (2020). Functional condition of cardiovascular system of highly skilled rowers in the process of intensive competitive activity. *Sports Medicine, Physical Therapy & Occupational Therapy*, 1, 49-60. <http://doi.org/10.32652/spmed.2020.1.49-60>.
- Waylung, W., Rusanova, O., Diachenko, A. (2019). Control for functional support of special work capacity of skilled rowers with account for specialization in kayaking and canoeing. *Theory and Methods of Physical Education and Sports*, 1, 92-100. <http://doi.org/10.32652/tmfvs.2019.2.92-100>
- Withers, R.T., Ploeg, G., Finn, J.P. (1993). Oxygen deficits incurred during 45, 60, 75 and 90-s maximal cycling on an air-braked ergometer. *European Journal of Applied Physiology*, 67(2), 185-91.
- Yang, M.T., Lee, M.M., Hsu, S.C., & Chan, K.H. (2017). Effects of high-intensity interval training on canoeing performance. *European Journal of Sport Science*, 17, 7, 814-820. <http://doi.org/10.1080/17461391.2017.1314553>.
- Zamparo, P., Capelli, C., & Guerrini, G. (1999). Energetics of kayaking at submaximal and maximal speeds. *European Journal of Applied Physiology & Occupational Physiology*, 80, 542-548.