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ORIGINAL SCIENTIFIC PAPER

Neurohumoral Components of Rapid Reaction Kinetics of the Cardio-Respiratory System of Kayakers

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Abstract

The article shows the influence of the neurogenic and humoral components of the reaction on the development of rapid kinetics of the cardiorespiratory system and the functionality of the kayakers during the loads of maximal and submaximal intensity. Research was performed on kayakers team of Jianshi and Shandong provinces (China), n=32. We did gas analysis (Oxycon mobile (Jaeger) metabolimeter) and ergometry (Dansprint). Test tasks included loads with maximum intensity of work for 10 s, 45 s and 120 s. The analysis of indicators of quantitative characteristics and relationships of response indicators maximum level of pulmonary ventilation (V_E), partial pressure of CO2 ($PaCO_2$), oxygen consumption (VO_2), equivalent of oxygen consumption (EqO_2), equivalent of CO2 emissions ($EqCO_2$), equivalent of partial pressure of CO2 ($EqPaCO_2$), which characterize the rapid kinetics of the cardiorespiratory system in the process of analyzing the functional support of the special working capacity of kayakers. This allowed us to determine the initial components of the reaction and the degree of their influence on the effectiveness of the functional support of the special working capacity of kayakers. Analysis of the reaction components indicates that specific indicators of the ratio of the concentration of carbon dioxide in arterial blood, as well as CO_2 emission and breathing reactions ($EqPaCO_2$ and $EqVCO_2$), can be used to assess the rapid kinetics of the cardiorespiratory system. Depending on the duration and intensity of the load, these reaction components also form the structure of the functional support of special performance, influence the development of power, economy and stability of the reaction. The informative characteristics of rapid kinetics are associated with the highest rates of the reaction of the cardiorespiratory system (breathing reactions) to an increase in the partial pressure of carbon dioxide and the release of CO_2 in the external respiration system. Normative model characteristics of $EqPaCO_2$ and $EqVCO_2$ can be registered during the 45 s test, when indicators of $EqPaCO_2$ and $EqVCO_2$ reach the highest values in a series of tests: $EqPaCO_2$ – 3.6±1.0. $EqVCO_2$ – 30.1±3.4. These indicators can be used as a characteristic of the components of the rapid reaction kinetics of the cardiorespiratory system.

Keywords: *functional capabilities, rapid kinetics, neurogenic stimulus, humoral stimulus, cardiorespiratory system of kayakers*

Introduction

At the core of the implementation of competitive activity in cyclic sports consists from integral manifestations of the functional support of special working capacity: speed of development of reactions, steady state of functions, compensation of fatigue (Mishchenko & Suchanowski, 2010).The reaction components form the structure of functional readiness and are combined into a system, where an increase in the effectiveness of each component leads to an increase in the effectiveness of the entire system (Lysenko, Shinkaruk, & Samuilenko, 2004).

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The special literature shows the influence of the rapid kinetics of the reaction of the cardiorespiratory system (CRS) on the structural components of the functional support of special working capacity (Ward, Lamarra, & Whipp, 1996). The quantitative and qualitative characteristics of fast kinetics have been substantiated in special literature as well (T_{50}HR, VO_2, VCO_2, V_E). The normative basis for the rapid kinetics of CRS has been brought in line with the gender, age, qualifications and specialization of athletes (Wang, Rusanova, & Diachenko, 2019).The individual reactive properties of the body play a special role, which is manifested in the magnitude of the body's response to specific physiological drives ("drives") (Mishchenko, Lysenko, & Vinogradov, 2007).

The issues of the implementation of stimuli of rapid kinetics of CRS were considered in the process of analyzing the conditions for the realization of neurogenic and humoral stimuli of reaction (Miyamoto, Nakazono, & Yamakoshi, 1987; Warren, 1987; Withers, Ploeg, & Finn, 1993). When considering the development of the initial part of the reaction of CRS, the issues of the influence of various degrees of concentration in arterial blood of carbon dioxide and oxygen and CO_2 emissions in exhaled air are considered (Burton, Stokes, & Hall, 2004). There is evidence in scientific literature that indicates that the achievement of peak synchronization of $EqCO_2$ and $PaCO_2$ indicates the respiratory compensation threshold (RCT) of metabolic acidosis during standard exercise with increasing intensity (Liu, Steinacker, & Stauch, 1995). Increased partial pressure on the vascular wall enhances chemoreceptor "neurogenic" stimulation of respiration. The next phase of development of function is humoral phase, which manifests itself when a high degree of "acute" load hypoxia is reached and hypercapnia is actively developed. This component of the response stimulates the peaks of the pulmonary ventilation response. Both neurogenic and humoral components of the reaction affect the formation of the structure of the initial part of the reaction of CRS (Mishchenko et al, 2007). The degree of influence depends on the individual reactivity of CRS of athletes, as well as the structure of training and the level of functional fitness of athletes.

In the scientific community, there is an understanding that the analysis of the structure of the initial part of the reaction of CRS makes it possible to accurately assess its effect on the rapid kinetics of the reaction and other components of the functional support of special performance. This will make it possible to clarify the means and methods for managing training and competitive loads. It also requires a special analysis, taking into account the intensity and duration of the load. Particular attention should be paid to assessing the informativeness of indicators of function development (changes in $PaCO_2$ and VCO_2) or the reaction of CRS on changes in function under the influence of intense stress ($EqPaCO_2$ and $EqVCO_2$).

Purpose. To determine the effect of neurohumoral stimuli of the rapid kinetics of the cardiorespiratory system on the functional support of the special working capacity of kayakers.

Methods

Subject. 32 qualified male paddlers, leading athletes of Jiangxi & Shandong provinces, age=23.8±2.3 years, training age=7.0±0.9 years.

All participants were informed of the requirements prior to the study and gave their written consent. The local research ethics committee in the spirit of the Declaration of Helsinki approved all procedures.

Research protocol

For standardizing the measurements of special performance, the "Dansprint" ergometer with Gas exchange Characteristics were recorded. The specialists of the Scientific Sports Management Research Centers in Shandong Province (Jinan) and Jiangxi (Nanchang) carried out the measurements of the reaction of the cardiorespiratory system.

Oxygen consumption ($\dot{V}O_2$), CO_2 production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$) were determined on a breath-by-breath basis using an Oxycon mobile (Jaeger) metabolimeter. The metabolic unit was calibrated a gas of known composition (16.00% O2, 4.00% CO2), respectively.

We used the following tests: "test 10 s", "test 45 s", "test 120 s":

In "test 10 s", the conditions for the realization of fast reaction kinetics were simulated. Measurements of indicators of the cardiorespiratory system were carried out within 10 seconds of the recovery period after exercise.

In the "test 45 s" conditions of a high degree of load hypoxia and respiratory compensation of metabolic acidosis were modeled. The indicators were recorded in the process of performing the exercise.

The "test 120 s" modeled the conditions for the development of fatigue and its compensation. The indicators were recorded in the process of performing the exercise.

Statistical Analysis

In order to assess and analyse the data received the Statistical Package (SPSS 10.0) was used. Descriptive statistics suggested defining arithmetical average - , standard deviation - SD, as well as medaine - Me, maximal (Max) and minimal (Min) indexes, 25 % and 75 % indices. Correlation analysis used. The data was verified in accordance with the normal distribution (applying the Shapiro WIlk criteria). If the data were normally distributed, then in order to define the statistical validity of differences Student Criteria was applied. In case when the data has not complied with the normal probability law non-parametric criteria of Wilkinson was applied to define the statistical validity of discrepancies. The error probability during the statistical analysis was set at the level of p=0.05 (significance level).

Results

Table 1 shows the quantitative and qualitative characteristics of CRS, which stimulate the kinetics of the initial part of the reaction and form the structure of the functional support of special working capacity. The table shows that all indicators had values that corresponded to the indicators of the functional readiness model of qualified kayakers. Individual differences (CV) are noteworthy in $PaCO_2$, VCO_2, $EqCO_2$, $EqPaCO_2$. CV parameters of $PaCO_2$ in "test 10 s", "test 45 s", "test 120 s" were in range of 10.0-11.0%; CV of $EqPaCO_2$ were significantly higher, 34.9%, 29.0%, 17.8% respectively. In the "test 45 s" the highest quantitative characteristics of the reaction of CRS were registered: upper quartile scores (75%) $EqPaCO_2$, $EqCO_2$ and VCO_2. At the same time, individual differences of specific indicators of CRS reaction and energy supply of work remained high.

Table 1. Indicators of the reaction of the cardiorespiratory system during the performance of tests of various duration and intensity among rowers on kayaks (n=32)

Data	V_E	$PaCO_2$	VCO_2	VO_2	EqO_2	$EqCO_2$	$EqPaCO_2$	V_E	$PaCO_2$	VCO_2	VO_2	EqO_2	$EqCO_2$	$EqPaCO_2$	V_E	$PaCO_2$	VCO_2	VO_2	EqO_2	$EqCO_2$	$EqPaCO_2$
	Test 10 s *							**Test 45 s ***							**Test 120 s***						
	79.9	41.0	2.9	40.8	29.2	28.2	2.2	126.9	38.7	4.4	49.7	37.2	30.1	3.6	123.2	35.9	4.0	54.2	39.3	30.6	3.5
Me	75.2	41.5	3.0	40.6	27.0	28.7	2.0	132.4	39.2	4.4	51.0	36.1	29.2	3.6	124.8	36.0	4.0	53.8	37.9	30.4	3.5
SD	21.9	4.5	0.7	8.6	7.4	3.3	0.8	25.7	4.3	0.8	6.0	7.4	4.0	1.0	20.1	3.6	0.5	7.4	9.1	3.3	0.6
min	43.4	32.3	1.6	26.1	20.8	21.8	1.2	77.7	31.2	2.7	34.9	24.3	24.1	1.9	82.4	30.1	2.9	41.4	24.8	25.2	2.2
max	124.3	48.7	4.3	56.0	50.2	34.2	4.2	172.9	46.4	5.8	60.0	53.0	40.3	5.3	159.7	42.5	5.1	68.0	58.9	37.6	5.1
25%	65.6	38.3	2.4	33.6	24.2	25.6	1.7	110.5	35.3	4.0	45.7	32.4	27.4	2.7	113.3	32.4	3.7	48.7	32.1	27.8	3.1
75%	95.0	43.5	3.1	47.0	33.3	30.4	2.4	144.3	42.0	4.8	53.8	40.5	32.3	4.4	136.5	38.8	4.4	60.3	45.2	33.2	3.8
CV	27.4	**11.0**	**24.3**	21.2	25.4	**11.9**	**34.9**	20.2	**11.1**	**17.5**	12.1	19.9	13.4	**29.0**	16.3	**10.0**	**13.5**	13.7	23.1	**10.8**	**17.8**

Legend: * – in "test 10 s measurements of indicators of the cardiorespiratory system were carried out within 10 seconds of the recovery period after exercise; in the "test 45 s" the indicators were recorded in the process of performing the exercise; in the "test 120 s" the indicators were recorded in the process of performing the exercise. The analysis was contacted of indicators maximum level of pulmonary ventilation (V_E), partial pressure of CO_2 ($PaCO_2$), oxygen consumption (VO_2), equivalent of oxygen consumption (EqO_2), equivalent of CO_2 emissions ($EqCO_2$), equivalent of partial pressure of CO_2 ($EqPaCO_2$)

Table 2 shows reliable correlations of indicators of CRS reaction to an increase in the concentration of carbon dioxide in arterial blood and CO_2 release in the external respiration system, registered by rowers in tests of various duration and intensity. The result of the analysis is the substantiation of a high degree of interconnection of indicators of the development of function, reaction to an increase in workload and the efficiency of energy supply of work (Table 2).

Table 2. Correlation relationships ($p<0.05$) of the indicators of the reaction of the cardiorespiratory system during the performance of tests of various duration and intensity in rowers on kayaks (n=32)

Data		V_E	$PaCO_2$	VCO_2	VO_2	EqO_2	$EqCO_2$	$EqPaCO_2$	V_E	$PaCO_2$	VCO_2	VO_2	EqO_2	$EqCO_2$	$EqPaCO_2$	V_E	$PaCO_2$	VCO_2	VO_2	EqO_2	$EqCO_2$	$EqPaCO_2$
		Test 10 s							**Test 45 s**							**Test 120 s**						
V_E	Test 10 s	-		0.9	0.7	0.5	0.6	0.9														
$PaCO_2$			-		0.5	0.5																
VCO_2				-	0.8	0.5	0.5	0.8														
VO_2					-		0.6	0.6														
EqO_2						-	0.5	0.5														
$EqCO_2$							-	0.6														
$EqPaCO_2$								-														
V_E	Test 45 s								-		0.9	0.6	0.6	0.6	0.96							
$PaCO_2$										-		0.7										
VCO_2											-	0.8	0.6		0.8							
VO_2												-										
EqO_2													-	0.9	0.7							
$EqCO_2$														-	0.6							
$EqPaCO_2$															-							
V_E	Test 120 s															-		0.9	0.5	0.7	0.8	0.8
$PaCO_2$																	-	0.5	0.7			
VCO_2																		-	0.7	0.7	0.6	0.5
VO_2																			-	0.6		
EqO_2																				-	0.7	0.5
$EqCO_2$																					-	0.8
$EqPaCO_2$																						-

Legend: The analysis was contacted of indicators maximum level of pulmonary ventilation (V_E), partial pressure of CO_2 ($PaCO_2$), oxygen consumption (VO_2), equivalent of oxygen consumption (EqO_2), equivalent of CO_2 emissions ($EqCO_2$), equivalent of partial pressure of CO_2 ($EqPaCO_2$)

Noteworthy is the high degree of correlation between $EqPaCO_2$ and specific indicators of pulmonary ventilation and energy supply of work ($EqVCO_2$ and $EqVO_2$) observed in all tests. During "test 120 s" $PaCO_2$ and $EqPaCO_2$ had a stable tendency to be related to the indicators of the efficiency of aerobic energy supply $EqVO_2$. The analysis also took into account the correlation dependence of $EqVO_2$ and VO_2.

It is important to note the fact that the indicators of function development ($PaCO_2$ and VCO_2) had the number of reliable connections of one and four in the "test 10 s", in "test 45 s" it was one and three, in "test 120 s" it was two and four; reactions of pulmonary ventilation to changes in function ($EqPaCO_2$ and $EqVCO_2$) had four and five, two and four, three and four, respectively.

The general trend is that the characteristics of the development of the function and reaction of pulmonary ventilation had high correlations between themselves and with $EqVO_2$ and VO_2. The most distinctly integral manifestations of the relationship between indicators of the initial part of the reaction of CRS and aerobic energy supply of work is shown in the "test 120 s".

Discussion

Currently, there is a clear understanding that the indicators of the reaction power of CRS and the energy supply of work do not provide complete information about the potential of the athlete, his readiness for maximum implementation of functional capabilities in the process of competitive activity. Special literature shows thatVO_2max, blood lactate concentration, maximum pulmonary ventilation and other characteristics of functional fitness, registered under standard protocol (Mac Dougall, Wenger, & Green, 1991),often differ from the reaction indicators noted in the process of overcoming the competitive distance (Diachenko et al., 2020).

In this regard, more and more attention is paid to the study of the components of the body's reaction, which provide stimulation of functions in the process of overcoming a specific competitive distance. These reaction components are part of physiological processes that stimulate functional capabilities under conditions of hypoxia, hypercapnia and accumulation of products of anaerobic metabolism (Garnacho-Castaño et al., 2019). They have an impact on the formation of the structure of the reaction of the functional support of the special working capacity of athletes (Mishchenko et al., 2007). In cyclic sports, the reaction components are clearly manifested in the process of training, steady state and compensation of fatigue (Vogler, Rice, & Gore, 2013; Nikonorov, 2015).

In the special literature, the possibilities of functions regulation during physical activity are shown based on the implementation of neurogenic (Vilaça-Alves et al., 2016) and humoral drives of the reaction (Bourgois & Vrijens, 1998). The latter is associated with the body's response to the development of hypoxia, hypercapnia and accumulation of products of anaerobic metabolism (Mishchenko et al., 2007). Optimization of neurohumoral regulation of functions affects the formation of the structure of the functional support of special performance, increases the reaction speed of power supply at the beginning of work (Ward et al, 1996), power of functional support during steady state period (Maté-Muñoz et al., 2015) and activates mechanisms to compensate for fatigue (Hill, 1993).

The problem is that the conditions of competitive activity in cyclic sports are accompanied by high energy power and work capacity, where transient processes and the associated conditions for the implementation of neurohumoral stimulation of the body rapidly change. At the same time, the quantitative and qualitative characteristics of neurohumoral regulation have been studied under conditions of standard loads (de Klerk et al., 2020). Analysis results provide informative characteristics of CRS reactivity, which allow to determine the predisposition of an athlete to work of a certain duration and intensity (Michael, Rooney, & Smith, 2008; Paquette, Bieuzen, & Billaut, 2018). The issues of the influence of CRS stimulation on the development of functions and the implementation of competitive activity have not been sufficiently studied. This is due to insufficient knowledge about the structure of the reaction and the choice of specific operating modes, aimed at the implementation of stimuli of reactions in specific conditions of training and competitive activity. This problem occurs especially often when it comes to differentiating between neurogenic and humoral stimulation. These criteria are not sufficiently developed and are little used in the training load management system. As a rule, we are talking about complex stimulation, when neurogenic and humoral influences are closely interrelated. External integral manifestations of the reaction are used as assessment criteria, namely: function increase amount ($T_{50}HR$, VO_2, CO_2, V_E) (), fatigue compensation response and related differences in function during steady state and fatigue development ($V_E{\cdot}VCO_2^{-1}(V_E{\cdot}VO_2^{-1})_{\text{ofsteady state}}$ / $V_E{\cdot}VCO_2^{-1}$ $(V_E{\cdot}VO_2^{-1})_{\text{period of fatigue development}}$ x 100%) ()etc.

The article presents the possibilities of optimization of the functional support of the special working capacity of kayakers based on the analysis of neurogenic and humoral stimuli during the initial part of CRS reaction. During the analysis, we took into account that the rapid kinetics of CRS is considered as a trigger mechanism for the regulation of functions in the process of intense physical activity. The degree of realization of fast kinetics affects the formation of the structure of the functional support of the competitive distance.

Quantitative characteristics and relationship of V_E, $PaCO_2$, VCO_2, VO_2, EqO_2, $EqCO_2$ and $EqPaCO_2$showed the effect of neurohumoral stimulation on the rapid kinetics and the formation of the structure of the functional support of work during loads with maximal and submaximal intensity. The development of this process goes through two stages: neurogenic, when the process of neurohumoral regulation of functions is associated with an increase in the concentration of carbon dioxide in arterial blood and humoral, when the development of function is influenced by the rate of CO_2 excretion. It has been shown in the special literature that the achievement of synchronization of these processes is indicative of respiratory compensation (RCP) of metabolic acidosis. This is one of the aspects of the manifestation of the reactive properties of the organism, as well as a component of the rapid kinetics of CRS. The results of the analysis confirm the data of special literature and at the same time indicate that informative criteria for rapid kinetics are indicators of the reaction of CRS to changes in $PaCO_2$ andVCO_2. Their quantitative characteristics are shown during evaluation of $EqPaCO_2$ and $EqVCO_2$. Most informative characteristics of $EqPaCO_2$ and $EqVCO_2$are the indicators registered in the "test 45 s". This test shows the highest scores of V_E, $EqPaCO_2$ and $EqVCO_2$, when the highest level of pulmonary ventilation response is reached.

The given components of the initial part of the reaction stimulate the rapid kinetics of CRS, form the prerequisites for a quick and adequate reaction of energy supply to work in conditions of hypoxia, hypercapnia and accumulation of products of anaerobic metabolism. This creates conditions for optimizing the structure of the functional support of special working capacity and more efficient use of the functional reserves of the body.

Conclusion

The influence of the neurogenic and humoral components of the reaction on the increase in the rapid kinetics of the cardiorespiratory system and the development of the functional capabilities of kayakers under conditions of maximal and submaximal intensity loads was shown. Analysis of the reaction components indicates that specific indicators of the ratio of the concentration of carbon dioxide in arterial blood, CO_2 excretion and breathing reactions ($EqPaCO_2$ and $EqVCO_2$) can be used to assess the rapid kinetics of CRS. Depending on the duration and intensity of the load, these reaction components form the structure of the functional support of special performance and influence the development of power, economy and stability of the reaction. Normative model characteristics of $EqPaCO_2$ and $EqVCO_2$ can be recorded during the "test 45 s" when the indicators of $EqPaCO_2$ and $EqVCO_2$ reach their maximum values.

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Conflict of Interest
The authors declare that there are no conflicts of interest.

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