The comparison of C1 paddling functional test and arm crank ergometry in canoe slalom elite athletes

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Abstract

Background: *Recently, there have been rising demands on the specifics of functional load testing, which should with its motor structure correspond or at least draw near the sport specialization. However, evaluation of specific forms of diagnostics is very pure in canoe slalom.*

Objective: *The aim of the study was to compare a physiological response based on results in graded functional test when paddling in a single-canoe (C1) and results reached in the standardized arm crank ergometry.*

Methods: *The research sample consisted of 6 elite men Czech single-canoeists, members of Czech senior national team and the Czech national team up to 23 years. Their average weight was 79.7 ± 6.6 kg, height 183.4 ± 6.6 cm and age 23.6 ± 3.9 years.*

Results: *When comparing the result values of physiological indicators measured in both functional tests, we have found out significant differences (statistical and substantive) in variables: peak oxygen uptake (VO_{2peak}; $p = 0.00$; 15.1%), peak ventilation (VE_{peak}; $p = 0.06$, 11.1%), heart rate (HR; $p = 0.02$; 5.7%), respiratory rate (RR; $p = 0.18$; 9.3%), tidal volume (V_T; $p = 0.00$; 18.8%) and respiratory exchange ratio (RER; $p = 0.26$; 4.0%). With the exception of respiratory rate, significantly lower values of all physiological variables were found in on-water testing (C1). Although there was a strong correlation between the VO_{2peak} indicators ($r = 0.79$) found between paddling and crank ergometry, this relationship cannot be considered significant ($p = 0.06$) due to the small research sample.*

Conclusions: *The physiological responses of on-water testing and of crank ergometry are different. While VO_{2peak} in arm crank ergometry was 54.2 ml.kg.min^{-1}, in paddling on water it was only 46 ml.kg.min^{-1} ($p = 0,00$). Big inclusion of deep and surface abdominal muscles, which is necessary for technically efficient paddling, leads to lower ventilation, which is logical predisposition of VO_{2peak}. To evaluate the paddling test and finding external validity of arm crank ergometry in C1 category, it would be suitable to realize testing with a bigger research sample in future studies. Performance in C1 is probably more dependent on local strength endurance of upper limbs rather than on global respiratory fitness.*

Keywords: *C1, canoe slalom, Cortex Metamax 3B, oxygen uptake*

INTRODUCTION

Canoe slalom is a sport discipline which performance depends on the fastest run through a course with a combination of downstream and upstream gates hanged above the river rapids. We distinguish two categories in canoe slalom – kayak and canoe. The kayak competitor sits in the kayak and has a double-bladed paddle. The canoe competitor kneels in the canoe and has a single-bladed paddle. We distinguish single (C1) and double (C2) canoes (www.canoeicf.com).

The difficulty of water terrain and gate combination is a variable which requires high demands on technical competences of competitors of all categories. Changing competition conditions, hard competitive environment and high error rate in performance put high demands on tactics and mental characteristics of a competitor. However, physical demands do not stand apart. Besides developed strength-speed abilities the competitor in canoe slalom (same as in flat water canoeing or rowing) needs to have high aerobic and anaerobic capacity (García-Pallarés et al., 2009; 2011). The performance is usually 90 to 110 seconds long and 52 % of energy expenditure is covered through anaerobic metabolism (Heller et al., 1995).

The essential physiological endurance indicator is maximal oxygen uptake (VO_{2max}). VO_{2max} is usually measured during progressive activity of lower limbs, the most often during running. In case of sport-specific testing forms or in case of arm crank ergometry we talk about peak oxygen uptake (VO_{2peak}), because it reaches approximately up to 85% VO_{2max} (Heller & Vodička, 2011).

The physiological determinants of endurance abilities have been researched in speed canoeing in detail, especially in kayak category. The survey study by Michael et al. (2008) has indicated that VO_{2peak} of speed canoeist reaches about 58 $ml.kg.min^{-1}$ during specific forms of testing. It means during the work of upper limbs and trunk, and this result was confirmed by Buglione et al. (2011) in case of speed canoe racers.

Although the arm crank ergometriy has been often used in case of testing speed kayakers (e.g. Bergh et al., 1976; Pendergast et al., 1979; Tesch, 1976, 1983; Tesch & Lindeberg, 1984), from the point of view of movement structure and muscle chains inclusion, it is more suitable to use the paddle simulator (Kračmar, Bačáková, Chrástková et al., 2016). Therefore, spiroergometry started to use later the paddle simulator (e.g. Fry & Morton, 1991; Billat et al., 1996; Bishop et al., 2002; Štěrba, 2016). However, the most suitable is the mobile spiroergometric testing when paddling on flat water (Michael et al., 2008), in which we can ensure the similarity of movement structure in almost 100%. In kayakers results measured in arm crank ergometry and during paddling on a simulator or on flat water (Busta, Bílý, Suchý & Kovářová, 2017; Carré, 1994) are very similar and we can state that arm crank ergometry is for kayakers a valid diagnostic means. We still do not know how it is in case of C1 category. Its movement structure is in comparison to asynchronous arm crank ergometriy obviously very different and there are no relevant studies comparing physiological demands of highly standardized arm crank ergometry and paddling in a canoe (C1 category).

The aim of this study was to compare the testing procedures of the two graded load test – standardized arm crank ergometry (Heller & Vodička, 2011) and graded paddling test in C1 on flat water. By comparing results we will learn more information about the relevancy of the diagnostic usage of the arm crank ergometry in C1 and about physiological demands of the C1 category, which is distinguished from the K1 category by a lower stroke frequency and higher strength demands for a stroke (Bílý, 2002) and which has not been researched a lot up to now.

AIM

To compare the physiological response between the graded functional test when C1 paddling and the standardized arm crank ergometry.

METHODS

The study researched and compared physiological response of two functional load tests. The research was realized in the autumn phase of the preparatory period of the year training cycle of water slalom races in two following days. The research sample consisted of 6 men members of senior and U23 Czech national teams (79.7 ± 6.6 kg; 183.4 ± 6.6 cm; 23.6 ± 3.9 years). First, they were tested on the push-up ergometer in the biomedical laboratory of the Faculty of Physical Education and Sport (Charles University). The following day canoe racers were tested when paddling on flat water in Prague Troja. The research has been approved by the Ethical committee of Charles University, Faculty of Physical Education and Sport and it is in agreement with the Declaration of Helsinki.

The arm crank ergometry (Figure 1) was realized according to the standardized load protocol (Heller & Vodička, 2011). Prior the own test, the measuring facility was adjusted according to the somatic parameters of the tested person and thorough warm-up. The own test was realized according to the standardized scheme:

- 4 minutes in easy and moderate pace, the load size: W = 2*weight of the tested person.
- Measured minute of rest.
- The graded load test up to "vita maxima". The intensity of the first stage was counted: W = 2.5*weight.
- At the end of every minute the performance grew up in 20 W (Table 1) with the requirement to keep the set speed of the ergometer.
- The test was finished with the subjective exhaustion of the tested person. Related to the sample homogeneity the final time was very similar.

Table 1: Protocols of load tests – grades of load intensity

		Arm crank ergometry	**On-water paddling (C1)**
Load grade	Test time (min)	Load intensity (W)	Seed ($km.h^{-1}$)
1^{st} grade	$0–1^{st}$	2,5*weight	v_{max} . 0.65
2^{nd} grade	$1^{st}–2^{nd}$	2,5*weight + 20	v_{max} . 0.70
3^{rd} grade	$2^{nd}–3^{rd}$	2,5*weight + 40	v_{max} . 0.75
4^{th} grade	$3^{rd}–4^{th}$	2,5*weight + 60	v_{max} . 0.80
5^{th} grade	$4^{th}–5^{th}$	2,5*weight + 80	v_{max} . 0.85
6^{th} grade	$5^{th}–6^{th}$	2,5*weight + 100	v_{max} . 0.90

Figure 1 Test of arm crank ergometry

The load test on flat water was realized according to the same scheme as in case of kayak racers (Busta et al., 2017):

- A thorough individual warm-up and warm-up on a canoe.
- Measurement of maximal speed in 20 metres sprint in a canoe with flying start by Speed Coach GPS-2 system (www.nkhome.com).
- The five-minute recovery.
- Placement of sport tester and spiroergometer on tested person's body, control of measuring functions and matching the counted speeds to individual intensity grades (Table 1).
- Measured four minute training (1^{st} and 2^{nd} grade of intensity).
- The measured minute of rest.
- The graded load test up to "vita maxima". Intensity of the first grade was set by an equation: $v = v_{max} * 0.65$.
- At the end of every minute the tested person was asked to increase the speed about 5% (corresponds to the 1^{st} load test), the tested person was always told the concrete required run speed corresponding to counted load grade.
- The test was finished by subjective exhaustion of the tested person. Related to the sample homogeneity the final time was very similar.

Table 2: Physiological parameters measured in tests

Measured parameter	Abbreviation	Units
Peak oxygen uptake	VO_{2peak}	$ml \cdot kg^{-1} \cdot min^{-1}$
Peak ventilation	VE_{peak}	$l \cdot min^{-1}$
Respiratory exchange ratio	RER	
Respiratory rate	RR	$breaths \cdot min^{-1}$
Tidal volume	V_T	$l.breath^{-1}$
Heart rate	HR	$beats \cdot min^{-1}$

Heart rate was measured by the sport tester Polar RS800 (www.polarcz.cz). To measure the further functional parameters (Table 2) we have used the spiroergometric instrument Metamax 3B by the German company Cortex (www.cortex-medical.com). In relation to negative influences of city buildings on telemetric signals we have used "off line" regime of the Metamax instrument, which is suitable for testing in terrain conditions. Spirometer does not emit data "on line" to the running computer, however, it saved them to its external memory. Data were later extracted to the further analysis. The GPS-2 system was placed in front of the canoe tested person so he could see it well when paddling (Picture 2, 3) and could determine well his speed.

Figure 2 and 3 Canoe racer with the measuring instrument and during the own load test

Statistical Analysis: Basic statistical characteristics of individual parameters are presented as means and standard deviations. To analyse relations between measured functional parameters and significant differences between them we have used Pearson correlation coefficient and paired t-test (Hendl, 2012) in relation to keeping the presumption of normal data distribution. Besides the statistical significance we have also evaluated the absolute substantive significance expressed in units of measurement. We have also observed the percentage difference between average result values measured during arm crank ergometry and during paddling in a canoe.

RESULTS

The Table 3 shows the average result values of functional parameters gained in test on water (OW) and during arm crank ergometry (CE). Statistically we evaluate the difference between them.

Table 3: The result values of functional parameters in both tests and their statistical evaluation

	Units	Average	SD	Values of T-test		Pearson correlation coefficient		Difference (%)
				T	P	r	p	
VO_2peak (OW)	ml.kg.min^{-1}	46.0	3.46	−9.36	0.00	0.79	0.06	−15.1
VO_2peak (CE)	ml.kg.min^{-1}	54.2	2.71					
RER(OW)		1.19	0.07	1.29	0.26	−0.38	0.46	−4.0
RER(CE)		1.24	0.04					
VEpeak (OW)	l.min^{-1}	133.6	24.73	−2.41	0.06	0.75	0.08	−11.1
VEpeak(CE)	l.min^{-1}	150.2	23.15					
HR(OW)	beats.min^{-1}	173.2	5.67	−3.32	0.02	−0.33	0.53	−5.7
HR(CE)	beats.min^{-1}	183.7	3.72					
RR(OW)	breath.min^{-1}	64.3	7.06	1.58	0.17	0.46	0.36	9.3
RR(CE)	breath.min^{-1}	58.8	9.00					
V_T(OW)	l.breath^{-1}	2.1	0.24	−5.54	0.00	0.46	0.36	−18.8
V_T(CE)	l.breath^{-1}	2.6	0.12					

OW = on water testing (C1 paddling); CE = arm crank ergometry

The average result values of all observed functional parameters, with the exception of RER and RR, were during paddling on flat water lower in the rate 5.7 to 18.8 %. Differences of these parameters were evaluated as statistically significant.

While VO_{2peak} in arm crank ergometry was 54.2 $ml.kg.min^{-1}$, in paddling on water it was only 46 $ml.kg.min^{-1}$. Canoe racers reached when paddling approximately about 8 $ml.kg.min^{-1}$ (15.1%) lower oxygen uptake. This difference was evaluated as statistically significant and we found it also substantive significant. The logical predisposition of lower VO_{2peak} is lower ventilation. Single canoe racers reach when paddling higher respiratory rate, but the maximal pulmonary ventilation is in average lower about 16,5 $l.min^{1}$.

In parameters VO_{2peak} and $VE_{peak,}$ measured in test on water and in arm crank ergometry, we have found high correlation value ($r = 0.79$; $p = 0.06$, resp. $r = 0.75$; $p = 0.08$), this relationship is on the border of statistical significance.

The lower VO_{2peak} together with lower values of VE_{peak} and HR (difference 10.5 $beats.min^{-1}$) corresponds to lower physiological answer during maximal load on water.

DISCUSSION

Although in parameters VO_{2peak} and VE_{peak}, measured in test on water and in arm crank ergometry, we have found high correlation value ($r = 0.79$; $p = 0.06$, resp. $r = 0.75$; $p = 0.08$), this relationship is on the border of statistical significance. To state that there is a significant relationship between the same variable in two different tests with the 95% probability, we need higher correlation values or a bigger research sample. We can only suggest that canoe racers with higher VO_{2peak} in arm crank ergometry probably reach higher VO_{2peak} in paddling in a canoe, at the same time they reach on water approximately about 15% lower oxygen uptake. The lower VO_{2peak} together with lower values of VE_{peak} and HR (difference 10.5 $beats.min^{-1}$) corresponds to lower physiological answer during maximal load on water. Therefore, the performance in C1 depends probably more on local strength endurance rather than on global cardiorespiratory fitness represented mainly by VO_{2peak}.

Although single canoe racers reach when paddling higher respiratory rate, the maximal pulmonary ventilation is in average lower almost about 17 $l.min^{1}$. These differences can be explained by breathing in the rhythm of paddling. The higher frequency of paddling leads probably to higher frequency of breathing. However, such breathing is shallower, which corresponds to the 19 % difference measured in tidal volume parameter. The more shallow breathing can be explained by rather big inclusion of deep and surface abdominal muscles, which help to create the propulsion strength when paddling and its effective transfer in the canoe speed. Their inclusion is necessary for keeping balance and postural stability necessary for technically efficient paddling.

Single canoe races reached during paddling significantly lower values of functional parameters than kayak racers in the same test (Busta et al., 2017). These values were, moreover, in comparison to kayak racers significantly different from the standardized arm crank ergometry. The movement pattern of kayak paddling is of course very similar to arm crank ergometry (asynchronous work of arms). Despite this fact we were surprised to what extent were the result values of functional indicators in the category C1 different.

In case of speed kayak racers VO_{2peak} was measured in general and specific tests in many studies. Their systematic survey discuss studies by Michael et al. (2008) and later Li (2012). In the C1 category there is only a study by Buglione et al. (2011). The single canoe racers reached in this study very similar values of VO_{2peak} as kayak racers (4.75 $l.min^{-1}$ vs. 4.79 $l.min^{-1}$). Therefore the speed canoe racers reach probably similar VO_{2peak} values during their performance as kayak racers. It is necessary to add that Buglione et al. (2011) tested 46 kayak racers and only 5 single canoe racers. To prove the similarity of VO_{2peak} it is necessary to realize further studies even in case of speed canoeing.

In canoe slalom C1 racers reach lower VO_{2peak} values when paddling than kayak racers. While kayak racers reached in testing on water the average VO_{2peak} 56 $ml.kg.min^{-1}$, the single canoe racers reached the average oxygen uptake values about 10 $ml.kg.min^{-1}$ lower. This difference can be explained by including a smaller amount of muscles in comparison to slalom kayak and speed single canoe. The performance in C1 in canoe slalom is probably dependent more on local strength endurance, rather than on global cardiorespiratory fitness represented by the VO_{2peak} indicator. Or the performance in C1 category is probably highly determined by the level of special endurance and less then by the level of general endurance. We talk here about different physiological requirements which accurate understanding is of course key for optimization the training process in the area of fitness skills.

The only indicator which reached higher values in paddling in C1 than in arm crank ergometry was the respiratory rate. However, the higher RR did not lead to overall higher minute pulmonary ventilation, mainly due to lower tidal volume. RR is probably closely related to paddling frequency. The expiratory phase of the breath cycle is connected to finishing the pull phase of the paddling cycle. The necessity of deep and surface abdominal muscles inclusion for keeping balance, postural stability, creation of propulsion strength and efficient transformation in canoe locomotion speed, does not enable the deep breathing. This study questions (lowers) external validity of using arm crank ergometry as a diagnostic instrument in case of C1 category. However, it does not refuse it completely. The correlation relationship measured in the most important parameter VO_{2peak} ($r = 0.79$) indicates that in case of this variable there is probably a strong relationship between the realized tests. However, this relationship cannot be evaluated as statistically significant ($p = 0.06$) due to a small research sample. To evaluate the paddling test and finding external validity of arm crank ergometry in C1 category, it would be suitable to realize testing with a bigger research sample in future studies.

CONCLUSIONS

The physiological responses of on-water testing and of crank ergometry are different. While VO_{2peak} in arm crank ergometry was 54.2 $ml.kg.min^{-1}$, in paddling on water it was only 46 $ml.kg.min^{-1}$ ($p = 0{,}00$). Big inclusion of deep and surface abdominal muscles, which is necessary for technically efficient paddling, leads to lower ventilation, which is logical predisposition of VO_{2peak}.

While there has been proved a great similarity of physiological response in the graded load test on an arm crank ergometer and in paddling on flat water in K1 category (Busta et al., 2017), it has not been proved in C1 category. Differences can be explained by different physiological requirements of both categories – performance in C1 is probably more dependent on local strength endurance of upper limbs rather than on global respiratory fitness.

The arm crank ergometry in C1 category cannot be recommended as a diagnostic method, which could bring us very similar values to those competitors reach in real performance in a canoe.

Even though the asynchronous work of upper limbs in arm crank ergometry can be substituted by synchronous arm work, the similarity of the motor structure stay still low. A suitable laboratory method instead of arm crank ergometry could be a test on the canoe ergometer. Still, we can expect problems with different inclusion of some muscle groups (Kračmar et al, 2016), the final values will probably be probably negative influenced by these differences.

Therefore we find the future in terrain functional testing during the specific activity of paddling. It brings new possibilities of evaluating functional parameters and can soon become a part of diagnostic batteries for evaluation of training level. Specific functional testing can significantly contribute to more efficient operation of the training process and helps to better explain the physiological demans of the canoe slalom, epsecially the C1 category.

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