Anthropometric, physiological and performance profiles of Elite and Sub-Elite Canoe Slalom Athletes

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Abstract

The purposes of this study were to determine the anthropometric, physiological and performance characteristics of elite and sub-elite canoe slalom athletes and to determine the relationship between these characteristics and performance in selection races for the Olympic Games in Rio de Janeiro 2016. Eighteen male single-canoe (C1) slalom athletes (20.9±5.1yr) performed a battery of tests including anthropometric parameters and somatotypes, upper-body anaerobic power (Wingate test), maximal muscular strength (bench-press, bench-pull, handgrip dynamometry), aerobic power (treadmill running test), and specific on-water tests (40m and 200m sprints with spins). Additionally, Spearman's correlation were conducted and multiple regression analysis was used to determine the relationship between the results of on-water tests and the final race rankings.

Canoe slalom athletes were 180.6±4.1cm tall and 74.4±4.6kg with an ectomorphic mesomorph somatotype (1.6-4.9-2.8). They are further characterized by a treadmill VO2max of 62.7±3.0ml·kg·min-1 and high values of anaerobic upper-body peak power (9.4±1.1W·kg-1) and mean power (7.4±0.7W·kg1). Their bench-press 1 repetition maximum (1RM) was 95±15kg, bench-pull 1RM was 93±9.5kg, and handgrip strength was 49.3±7.5kg. Race performance was significantly correlated (p<0.01) with bench-press 1RM (rs=0.60), normalized upper-body peak and mean anaerobic power (rs=0.57), and on-water tests (rs=0.62 to 0.85). By multiple regression analysis, it was possible to predict race ranking based on water performance tests (R2=0.78; SEE=2.75).

The results of this study can assist coaches, and trainers in racionalization of training programmes for canoe slalom athletes.

Key words

C1, canoeing, white water, Olympic, kayaking

Souhrn

Cílem studie bylo stanovit antropometrické, fyziologické a výkonové charakteristiky vrcholových a výkonnostních vodních slalomářů a zjistit vztahy mezi těmito charakteristikami a výkonností v nominačních závodech na Olympijské hry v Riu de Janeiru 2016. Výzkumný soubor složený z 18 závodníků kategorie single-canoe (C1) ve věku 20,9±5,2 vykonal baterii testů zahrnující měření antropometrických parametrů a somatotypu, anaerobního výkonu horních končetin (Wingate test), maximální svalové síly (bench-press, přítah a ruční dynamometrie), aerobního výkonu (spiroergometrický stupňovaný test na běhátku) a sprintů na klidné vodě s otočkami na vzdálenost 40 a 200m. Vztah s výkonností v závodech byl zjišťován prostřednictvím Spearmanovy pořadové korelace. K zjištění možností predikce výkonnosti v závodech na základě

uvedených parametrů byla využita vícenásobná regresní analýza.
Tělesná výška a hmotnost kanoistů činial 180,6±4,1cm, resp. 74,4±4,6kg, z hlediska somatotype je charakterizujeme jako ektomorfní mezomorfy. Dále jsou charakterističní hodnotou aerobního výkonu VO2max 62,7±3,0ml·kg·min-1 a vysokou hodnotou maximálního (9,4±1,1W·kg-1) a průměrného (7,4±0,7W·kg1) výkonu dosaženého při anaerobní práci horních končetin. Maximální síla prokázaná při 1 opakovacím maximu (OM) cviku bench-press činila 95±15kg, při cviku přítah 93±9.5kg a při maximálním stisku ruky 49,3±7,5kg. Výkonnost v nominačních závodech byla významně (p<0,01) s 1OM cviku bench-press (rs=0,60), normalizovaným maximálním a průměrným výkonem při Wingate testu horních končetin (rs=0,57) a testy na vodě (rs=0,62-0,85). Výkonnost v nominačních závodech je možné predikovat na základě 3 výsledků při sprintech na klidné vodě prostřednictvím vícenásobné regresní analýzy (R2=0,78; SEE=2,75).

Klíčová slova
C1, kanoistika, divoká voda, Olympiáda

Introduction

Since 1992, the Olympic discipline of canoe slalom has been contested on a whitewater course with athletes navigating through a combination of upstream and downstream gates. According to the rules, there are two main types of boats for a single competitor: kayak (K1), which is performed in a seated position and a paddle with two blades, and canoe (C1), which is performed in a kneeling position and a paddle with one blade (International Canoe Federation, 2017). Depending on the length of the course, difficulty of the rapids, and number of gates (18-25), the duration of an official canoe slalom competition can range from 90 to 120s (Nibali, Hopkins & Drinkwater, 2011). To paddle at maximal intensity for 90 to 120 s, it is likely that a multitude of physical skills are required such as aerobic and anaerobic power, strength, coordination, and speed (Zamparo et al., 2005).

But scientific knowledge about physical requirements, ability level of top-performance athletes and relationships between condition and race performance is still insufficient. While in the canoe sprint discipline there is a number of relevant complex studies (e. g. Akca & Muniroglu, 2008; Hamano et al., 2015; McKean & Burkett, 2009; Sitkowski, 2002; Van Someren & Howatson, 2008) and similar study was made in canoe polo (Alves et al., 2012) and even in case of outrigger canoe paddlers (Humpries et al., 2000), in canoe slalom we can find only sectional studies such as the study by Ridge et al. (2007) about morphology, Bílý et al. (2012) about body structure or about bioenergetics of K1 (Zamparo et al., 1999; 2005). In addition, most studies in canoe sprint and canoe slalom is about K1 category, but C1 category is different and there is still lack of C1 data. Considering the relative novelty of this sport and limited scientific literature, mainly in the C1 category, the purposes of this study were to determine the anthropometric, physiological, and performance characteristics of elite and sub-elite canoe slalom athletes and to determine the relationship between these characteristics and performance in selection races for the Olympic Games in Rio de Janeiro 2016.

Methods

Participants (Subjects)

Eighteen males from the Czech Republic (20.9±5.1yr, range = 17 to 32), who were competing in selection races for the 2016 Olympic Games in Rio de Janerio, participated in the study. All of these athletes were ranked among the top 25 Czech C1 competitors. Among these competitors was the complete representation of the senior (n=3), U23 (n=3), and junior (n=3) national teams, with one senior team member eventually competing in the Olympic Games. To be included in the study, participants must have logged at least 400 self-reported of on-water and dry-land training hours (e.g. technical, conditional, and tactical training).

The athletes signed an institutionally approved informed consent form after they had received a verbal and written explanation regarding the procedures of the testing procedures. For participants under the age of 18, written consent was provided by the parent or legal guardian. The research was approved by the university's local ethics committee.

Study design

Four weeks before the Olympic Games selection races, all athletes perfomed the three-day testing battery according to the timetable in Table 1. We evaluated selected conditioning indicators of anthropometry, muscular strength, upper-body anaerobic power and aerobic power and we determined the relationships between these indicators and overal race ranking in selection races on Olympic Games. In total, 4 selection races in two weekend took place, 3 individually best of them were counted in the overal ranking. In our research overal race ranking is a dependent variable, while tests values are independent variables.

Anthropometric measurement

Measurements were performed by a only one experienced investigator. All variables were measured on the right side of the body. The standard procedures for each measurement, as supported by International Society for the Advancement of Kinanthropometry and reported in Bloomfield et al. (2003) or Norton & Olds (1996) and used by Ridge et al. (2007) in morphological study of 74 canoe slalom 2000 Olympic Games athletes, were followed at all times. The somatotype was calculated using the method of Carter & Heath (1990) using the software programme Somatotype 1.2.5 (available from: http://goulding.ws/somatotype/). Body fat percentage was calculated by Pařízková (1977) prediction equition, which is based on measurement of 10 skinfolds by caliper of type Best with precision of 0.1cm (pressure on skinfold 28g/mm2).

Upper-body anaerobic power: Wingate test

The upper-body Wingate anaerobic test was performed as described by Inbar, Bar-Or & Skinner (1996) on modified arm-crank asynchrony ergometer Monark 4.0. Each test was proceded by a 5 minute warm-up at the inertial resistence of the equipment. After the 5 minute rest, the participants were verbally encouraged at the highest possible speed against a resistance of 4W.kg-1 (0,069kg. kg-1) according to Heller, Vodička & Příbaňová (2001). The highest external power output produced was used to represent the peak power, whereas the arithmetic mean of the power generated over the 30s corresponded to the mean power. Peak post-exercise lactate was measured 5 minute after test ending.

Muscle strength

Maximal dynamic strength was determined by a one-repetition maximum (1-RM) test. The test was conducted in standard and universaly accepted bench-press and pull-up (Baker & Newton, 2004) as was used by McKean & Burkett in case of canoe sprint kayakers (2009). Following a warm-up set, four sets of decreasing reps (4,3,2,1) and increasing loads (50,70,90,95%) were performed before a 1RM was attempted. Several attempts at 1RM were then made and if succesful, further weight was added until 1RM was reached. Three to four minutes rest was allowed between attempts. Tests were provided by certified coaches and research workers. Handgrip isometric strength was assesed with a conventional dynomemeter (Takei, model T.K.K.5401). The best of three consecutive trials with the dominant arm was considered for data analysis. A 30s recovery was allowed between trials.

Spiroergometry: maximal incremental test on a treadmill

A maximal incremental running test was performed on a treadmill (Quasar, Cosmos, Germany). After a 4 minute warm-up at 10km.h-1 and 12km.h-1, the speed was increased by 1km.h-1 every minute until exhaustion. The slope of the belt was 5%. The participants received strong verbal encouragement to continue as long as possible. Maximal oxygen uptake (VO2max) and another physiological indicators were measured by analyser Metamax 3B (Cortex, Germany). Heart rate was monitored during the test with a heart rate transmitter (model S810, Polar, Finland) coupled whith the Metamax 3B analyser. The maximum value of all physiological indicators was defined as the highest value obtained during the last 30s interval.

On-water testing

The on-water testing took place on the flat-water artificial channel in Račice (Czech republic), where standard conditions of zero flow and the same depth are set. Testing was not negatively affected by weather. After individual warm-up, participants starter in three sprints:

1. 40m with one spin after 20m on the side of paddling (on-hand spin),
2. 40m with one spin after 20m on the opposite side of paddling (back-hand spin),
3. 200m with two on-hand spins (after 40 and 120m) and two back-hand spins (after 80 and 120m).

Channel in Račice is intended for use of training and racing in rowing and canoe sprint. Therefore there are precisely marked distances in interval of every 10m by buoys. Every sprint started from the place and was measured by three experienced canoe slalom coaches of highest coaching license. Result of the sprint is the mean of two most similar times, objectivity correlation between two times was very high ($r=0.97-0.99; p<0.001$). Participants started

Table 1: Timetable of research procedures.

Day 1	17:00	Maximal strength testing (bench-press, bench pull)
Day2	9:00	Anthropometry measurement
	10:00	Takei handgrip dynamometry
		30s Wingate test of upper-body
	14:00	Spiroergometry: treadmill running test
Day3	9:00	On-water testing (40m with right spin, 40m with left spin and 200m whith two right spins and two left spins)

from the place and time has begun to be measured with the first starting movement. The blood sample from the finger to determine the lactate level was taken 5 minutes after the 200m was completed.

Statistical analysis

Data are expressed as mean, standard deviations and the range. To determine the relationship between race performance and test values was used Sperman´s correlation coeficient (rS). To predict the ranking in the races based on the results of on-water tests was used linear multiple regression analysis. Statistical significance was set at $p<0.01$.

Results

The selected anthropometric characteristics of the participants are presented in Table 2. Data from the strength, Wingate test and spiroergometry

Table 2: Anthropometric parameters.

Variable	Mean±s (range) of all athletes (n=18)	Correlation with race performance (rS)	Mean±s (range) of Senior Czech National Team (n=3)	Mean±s (range) of Junior Czech National Team (n=3)
Body height (cm)	180.6±4.6 (175.6-191.7)	-0,13	179.1±1.9 (176.6-181.1)	180.0±2.8 (176.8-183.7)
Body weight (kg)	74.4±4.6 (65.0-81.4)	-0.08	75.1±4.6 (69.2-80.4)	72.5±4.4 (68.1-78.5)
BMI (kg.m^2)	22.8±1.7 (18.6-25.8)	0.04	23.6±1.8 (21.4-25.8)	22.2±0.7 (21.7-23.2)
Sitting height (cm)	93.2±2.6 (87.1-99.7)	-0.28	93.1±1.3 (91.8-94.9)	92.7±1.2 (91.1-94.1)
Arm span (cm)	186.4±3.8 (181-195)	-0.41	189.2±4.7 (183.5-195)	187.0±1.6 (185.0-189.0

Humerus breadth (cm)	7.2±0.4 (6.1-7.8)	0.06	7.4±0.4 (6.8-7.8)	6.8±0.5 (6.1-7.2)
Femur breadth (cm)	10.0±0.5 (9.1-10.8)	-0.21	10.3±0.5 (9.6-10.7)	9.5±0.3 (9.1-9.9)
Flexed dominant arm girth (cm)	34.2±2.0 (30.5-37.6)	0.14	35.4±1.8 (33.1-37.6)	32.3±1.3 (30.5-33.5)
Flexed fominant forearm girth (cm)	27.1±1.3 (25.0-29.8)	0.07	27.7±0.6 (27.2-28.5)	25.6±0.7 (25.0-26.5)
Chest girth (cm)	95.2±4.6 (85-102)	0.33	98.2±3.0 (94-101)	91.9±2.9 (89.4-96.0)
Sum of 4 skinfolds (mm)	23.6±3.2 (17.5-28)	0.53	19.3±0.9 (18.0-20.0)	25.0±0.8 (24.0-26.0)
Endomorphy	1.6±0.3 (1-2)	-0.25	1.3±0.2 (1.1-1.5)	1.7±0.1 (1.5-1.8)
Mesomorphy	4.9±1.2 (3.1-7.1)	-0.02	5.7±1.2 (4.1-7)	3.6±0.5 (3.1-4.3)
Ectomorphy	2.8±0.9 (1.4-5.4)	-0.02	2.5±0.9 (1.4-3.7)	3.0±0.2 (2.8-3.2)
Sum of 10 skinfolds (mm)	52.8±7.5 (39.0-68.0)	0.41	44.0±3.7 (39.0-48.0)	55.7±1.2 (54.0-57.0)
Body fat (%)	8.6±2.0 (4.8-12.2)	0.43	6.3±1.1 (4.8-7.4)	9.3±0.3 (8.9-9.6)

are presented in Table 3. Data obtained from on-water testing are presented in Table 4. Differences between senior and junior National Team and relationships with the race performance are presented in these table too.

Czech C1 competitors had an average (Riegerová et al., 2010) body height and weight. Only three participants had body weight over 80kg (80.4-81.4). Senior Czech National Team (the absolutely best three competitors of Czech republic) are in in com-

Table 3: Strength, Wingate test and spiroergometry results.

Variable	Mean±s (range) of all athletes (n=18)	Correlation with race performance (rS)	Senior Czech National Team (n=3)	Junior Czech National Team (n=3)
Upper-body peak power (W)	703±111 (483-899)	-0.41	764±76 (657-831)	664±29
Normalized upper-body peak power ($W.kg^{-1}$)	9.4±1.1 (7.4-11.0)	0.57 (p<0,01)	10.2±0.6 (9.5-11.0)	9.2±0.8 (8.3-10.3)

Upper body mean power (W)	555±75 (398-679)	0.53	603±55 (537-671)	538±19.0 (511-555)
Normalized upper body mean power ($W.kg^{-1}$)	7.4±0.7 (6.1-8.6)	0.57 (p<0,01)	8.0±0.3 (7.8-8.4)	7.5±0.5 (7.0-8.2)
Wingate test lactate level ($mmol.l^{-1}$)	11.4±2.4 (7.9-16.4)	-0.37	12.1±3.2 (8.4-16.2)	12.8±2.6 (10.5-16.4)
1-RM bench-press (kg)	94.7±15.9 (80-130)	0.58 (p<0,01)	112.3±16.7 (90-130)	80.7±0.9 (80-82)
Normalized 1-RM bench-press ($kg.kg^{-1}$)	1.27±0.18 (1.04-1.61)	0.60 (p<0,01)	1.48±0.13 (1.30-1.61)	1.11±0.05 (1.04-1.17)
1-RM pull-up (kg)	93.0±9.5 (80-110)	0.21	98.7±7.5 (88-104)	85.0±2.9 (81-88)
Normalized 1-RM pull-up ($kg.kg^{-1}$)	1.23±0.08 (1.06-1.37)	0.33	1.31±0.04 (1.27-1.37)	1.17±0.06 (1.09-1.24)
Handgrip peak of dominant arm (kgf)	49.3±7.5 (36.4-63)	0.16	54.1±4.2 (48.3-58.0)	44.9±2.3 (42.4-47.9)
Normalized VO2MAX (ml. kg.min-1)	63.6±2.8 (57.1-67.1)	0.17	65.2±1.4 (64.1-67.1)	63.7±2.2 (61.8-66.7)
Running speed at VO2MAX ($km.h^{-1}$)	17.2±0.8 (16-18)	0.15	17.7±0.5 (17-18)	17.3±0.9 (16-18)
Maximum heart rate ($beats.min^{-1}$)	188±3.2 (183-196)	0.29	188±1.4 ((187-190)	190±4.3 (186-196)
Running test lactate level ($mmol.l^{-1}$)	11.2±0.5 (10.3-11.9)	0.20	11.3±0.2 (11.1-11.6)	11.3±0.5 (10.8-11.9)

parison with best juniors different in higher mesomorphy, lower body fat and bigger girths of arms and chest. They are more muscular, but they keep their weight low by reducing body fat. However, no significant relationships between anthropomtric parameters and race performance were found.

Significant and moderately strong relationship with race performance were found at normalized upper-body peak and mean power and with 1-RM and normalized 1-RM Bench-press. On the contrary, no significant relationship with race performance were found at VO2max and other spiroergometry indicators. Senior Czech National Team had biggest values of all measured indicators. The biggest diferences were found especially at upper-body peak power, 1-RM bench-press and handgrip.

The sprints signifacantly and strongly correlated with race performance. Correlation between sprints and race performance are the strongest correlations of all measured variables. Based on the three sprints we can predict race ranking by line-

Table 4: Results of on-water tests.

Variable	Mean±s (range) of all athletes (n = 18)	Correlation with race performance (rS)	Senior Czech National Team (n = 3)	Junior Czech National Team (n = 3)
40m sprint with 1 on-hand spin (s)	17.78 ± 0.84 (16.75 to 20.13)	0.62 (p<0.01)	17.28 ± 0.13 (17.15 to 17.47)	17.76 ± 0.71 (16.75 to 18.32)
40m sprint with 1 back-hand spin (s)	19.01 ± 1.00 (17.5 to 21.33)	0.86 (p<0.01)	18.14 ± 0.42 (17.63 to 18.66)	18.88 ± 0.58 (18.09 to 19.3)
200m sprint with two on-hand spins and two back-hand spins (s)	95.21 ± 4.54 (88.74 to 107.0)	0.80 (p<0.01)	92.53 ± 2.20 (90.02 to 95.38)	93.40 ± 3.30 (88.74 to 95.74)
200m test lactate level (mmol. l^{-1})	8.5 ± 2.1 (4.8 to 12.6)	0.40	8.6 ± 1.3 (6.8 to 10.0)	8.1 ± 1.1 (7.0 to 9.7)

ar multiple regression (R2=0.78; SEE=2.74). Shape of the regression eqation is: y=58.16+0.079x1-4.85x2+7.70x3, where x1 is the results of 40m sprint with one on-hand spin, x2 is the result of 40m sprint with one back-hand spin and x3 is 200m sprint with two on-hand and two back-hand spins.

Discussion

The purpose of this study was to determine the anthropometric, physiological and performance characteristics of elite and sub-elite canoe slalom athletes and to determine the relationship between these characteristics and performance in selection races for the Olympic Games in Rio de Janeiro 2016. By the watching the international race results (International Canoe Federation, 2017) Czech republic is one of the most successful countries in this sport, with a large base of competitors. Therefore our results could have a high general disclosure value.

Body height and body weight of Czech C1 athletes were very similar to other canoe slalom studies (Ridge et al., 2007; Bílý et al., 2013). In comparison with canoe sprint athletes (Ackland, Ong, Kerr & Ridge, 2003; Gutnik et al., 2015), canoe slalom athletes are smaller, lighter, and have less muscular somatotype, but they have propably very similar body fat percentage. In comparison with international elite canoe sprint athletes (Van Someren & Palmer, 2003; Van Someren & Howatson, 2008), Czech National Canoe Team has lower values of flexed dominant arm (35.4±1.8 vs. 36.9±1.3), forearm girth (27.7±0.6 vs. 31.3±1.1) and chest girth (98.2±3.0 vs. 106.9±2.4). But while the body weight of Czech best canoe slalom atletes was 75.1±4.6, best canoe sprint athletes had weight 85.5±5.0 kg.

To the best of our knowledge, limited research has been conducted on strength abilities and upper-body anaerobic power of canoe slalom athletes. Therefore we compare our data to those of similar sports. In comparison with succesful Brazilian Canoe Polo National Team (Alves et al., 2011), Czech National Canoe Slalom Team have much better upper-body anaerobic power, have higher upper body and arm strength and have lower body fat percentage too. But in comparison with elite canoe sprint Olympic and World-champinships succesful kayakers (Sitkowski, 2002) have admittedly lower upper-body anaerobic power and lower muscle strength too (Van Someren & Palmer, 2003). Maximal upper-body anaerobic power is significantly and highly (r=-0.84; p<0.001) correlated with canoe sprint performance in category K1 (Van Someren & Howatson, 2008) and according to Hamano et al. (2015) very probably with C1 category too. Therefore, it is not surprising that significant correlations between Wingate test indicators and race performance have been identified in our study too. In strength and anaerobic power indicators were found the biggest differences between elite senior and junior competitors.

Czech C1 competitors proved high values (57.1-67.1) of maximum oxygen uptake (VO2max). VO2max mean value (63.6±2.8) were similar to elite C1 (Buglione et al., 2011) and K1 (Michael, Rooney & Smith, 2008) canoe sprint athletes, but higher than canoe polo athletes (Alves et al., 2011), outrigger canoeists (Humphries et al., 2000), competitive surfers (Farley et al., 2012) or dragon boat team (Singh et al., 1995). However, VO2max did not correlate with race performance. After reaching of limiting level, it is not probably imporant for performance to have higher values of this indicator. And it´s probably more important to focus on strength develepment and development of non-specific and specific anaerobic endurance, high intensive training (Yang et al., 2017) respectively. In addition, Senior Czech National Team had higher values of all upper-body anaerobic and strength indicators than the Junior Czech National Team, but values of VO2max were not so different.

To predict race ranking in canoe slalom is very difficult task. Inter-race and inter-seasons correlations of race results are low (Nibali, Hopkins & Drinkwater, 2011). Therefore it is very good to explain 78% of ranking variability by regression model of three sprints. Trainers could better estimate the ranking of races and chances of yours competitors.

Conclusions

The results of this study show that upper-body anaerobic power and strength likely play a significant role in C1 paddling. Trainers should focus on very good development of. Differences in upper-body anthropemtric parameters and anaerobic power and strength existed between the senior and junior teams, highlighting the importance of maturation in C1 paddlers. From results of this study and in comparison with other studies we can say, that elite C1 competitors should be of average body height (175-180cm), body weight (75-80kg), should have very good development of upper body musculature, minimize the body fat, keep their somatotype dominantly mesomorphy and should excel by high anaeroic power and capacity. We can reccomend to focus on high intensive anaerobic training and on specific on-water training after achievement of VO2max level near to 60ml.kg.min-1. Highest correlation with race performance were detected in on-water specific tests. By multiple regression based on results of 40m sprints and 200m sprint we can predict race ranking (R2=0.78; SEE=2.75) fairly well.

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