ORIGINAL RESEARCH ARTICLE

Kinanthropometric and physiological differences between elite and sub-elite endurance kayak paddlers

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Abstract

Objective. To describe the kinanthropometric and physiological profile of South African endurance paddlers and to determine the differences in these profiles between successful and less successful paddlers.

Design. Twenty male kayak endurance paddlers who were categorised in 2 ability groups, elite (*N* = 11) and sub-elite (*N* = 9), underwent a battery of kinanthropometric and physiological (exercise and pulmonary function) tests.

Results. Sitting height expressed as a percentage of stature was the only kinanthropometric variable that showed a significant difference between the elite and sub-elite paddlers (53.6 ± 0.9 and 52.5 ± 1.2 cm, respectively, $p < 0.05$). The elite paddlers achieved a significantly higher relative maximum oxygen consumption (VO_{2max}) ($p < 0.05$), peak power output (PPO) ($p < 0.05$), PPO: weight ($p < 0.01$) and time to exhaustion ($p < 0.05$) during the incremental exercise test compared with the sub-elite paddlers. Of the pulmonary function assessments, only maximal voluntary ventilation (MVV) revealed a significant difference between the elite and sub-elite paddlers (220 ± 16.7 and 182 ± 39.7 $l.min^{-1}$, respectively, $p < 0.05$).

Conclusion. These results demonstrate that superior aerobic capacities and power distinguish successful from less successful endurance paddlers.

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Introduction

Scientific exercise and performance testing make it possible to identify specific kinanthropometric and physiological attributes necessary for success in elite sport. These attributes and their level of development vary between different sports and between different events within the same sport. Numerous studies have identified the kinanthropometric and physiological attributes necessary for success in endurance sports, such as running and cycling, but very few studies have identified those attributes important for success in kayaking.[3,12,14,15] This is partly due to the lack of kayak-specific laboratory tests and equipment that accurately simulate kayaking. The development of the K1 ergometer (K1 Ergo, Australian Sports Commission) made it possible to identify the attributes in the successful paddler more accurately than with previously used nonspecific laboratory tests such as arm crank ergometry.

A few studies, using kayak ergometers, have reported those factors important for success in sprint kayak events (200, 500 and 1 000 m distances). Endurance kayak competitions, however, are competed over 10 000 m and 42 km distances, and only 1 previous study[3] has reported those attributes important for kayak endurance success. It is not only important to identify these kinanthropometric and physiological attributes, but also to quantify the level of development of these attributes required for kayak endurance success. This may allow sport scientists to identify shortcomings in the paddler's abilities which can then be altered through specialised training programmes in order to improve endurance performance.

The aims of the present study were: (*i*) to describe the kinanthropometric and physiological profile of a selected group of South African endurance paddlers; and (*ii*) to determine if there are differences in the kinanthropometric and physiological attributes between successful and less successful paddlers.

Methods and procedures

Subjects

Twenty male kayak paddlers with a mean ± standard deviation (SD) age, weight and height of 28 ± 7 years, 80 ± 7 kg and 184 ± 7 cm, respectively, volunteered to take part in the study. Their competition level ranged from club to international level (3 subjects represented South Africa at the 2003 and 2004 World Marathon Championships). Each paddler had to meet the criteria of at least 4 years of competitive experience locally and/or internationally, participation in at least 2 major marathon events per year, for 4 consecutive years, and training at least 3 times per week. A subject was excluded from the study if he developed respiratory tract infection during the tests, could not perform the tests in the required time period due to any other illness, injury or other responsibilities, or showed an abnormality in resting pulmonary function. Each paddler agreed to all testing requirements and procedures by giving written consent. The 20 paddlers were divided into 2 ability groups. Paddlers who finished the Berg River canoe marathon (a premier multi-day race in the Western Cape) in the top 10 places in either 2002 or 2003, and/or represented the country in international competition in at least 1 of the 3 years prior to the study, were selected as the elite group (N = 11). All other paddlers were grouped as sub-elite paddlers (N = 9).

Experimental overview

The kinanthropometric measurements and pulmonary function measurements were taken during the first visit to the laboratory, followed by the incremental exercise test during a second visit on a separate day. All the subjects completed the laboratory tests in the same order.

Anthropometry

All anthropometric measurements were taken with subjects barefooted and dressed in tight-fitting clothes. Stature and sitting height were measured with a measuring tape mounted vertically to a wall perpendicular to the floor. A perspex board (32 x 23 cm) was placed firmly on the vertex of the head; the measurement was taken while the head was in the Frankfort plane and while the subject was taking a deep breath. Arm length was measured using a flexible steel tape (Lufkin, J Rabone and Sons, England) from the acromiale landmark to the dactylion landmark of the right arm. Measurements were taken to the nearest 0.1 cm. A modified version of the method of Hahn *et al.*[4] was used to measure arm span. An elastic measuring tape was mounted horizontally on the wall more or less at the shoulder height of a person of normal height. The subject was instructed to stand with his feet 3 - 4 cm apart and to abduct his arms 90°, with his torso pressed against the wall and his head turned sideways. The horizontal distance from the middle fingertip of the 1 hand to the middle fingertip of the other hand was taken as the measurement. All measurements were recorded to the nearest 0.1 cm.

Body mass was measured using an electronic scale (UWE BW-150 freeweight, 1997 model, Brisbane, Australia) to the nearest 0.1 kg. A Lange skinfold caliper (Cambridge Scientific Industries Inc., Cambridge, Maryland) was used to measure skinfolds at 6 sites, viz. triceps, subscapular, supraspinale, abdominal, front thigh and mid-calf. Each measurement was read 2 seconds after the release of the caliper trigger to the nearest 0.5 mm. Body fat percentage was calculated using the regression equation of Withers *et al.*[18] for body density (R^2 = 0.75, standard error of the estimate (SEE) = 0.0058) and the regression equation of Siri[13] for percentage body fat.

Five girth measurements were taken using a flexible Lufkin steel tape at the specific standardised sites. Measurements were taken to the nearest 0.1 cm. Breadths (to the nearest 0.2 cm) of the humerus and femur were measured using an anthropometric caliper (Fine Line Engineering, South Africa). Each subject's specific somatotype ratio was calculated from the skinfold, girth and diameter measurements according to the method of Heath and Carter.[5] Two consecutive scores were recorded for length (within 0.2 cm), for skinfold thickness (within 1 mm), and for weight (within 0.2 kg). The average of these 2 measurements was calculated as the final score. All the other measurements were taken once. The sitting height/stature ratio was calculated.

Incremental exercise test

A progressive incremental test to exhaustion was conducted to determine maximum oxygen consumption (VO_{2max}), maximum heart rate (HR_{max}), maximum minute ventilation (VE_{max}), maximum breathing frequency (f_{bmax}), lactate threshold (LT), ventilatory threshold (VT) and peak power output (PPO). The test was performed on a wind-braked kayak ergometer (K1 Ergo, Garran, Australia). The K1 Ergo was interfaced with specialised computer software which calculated and recorded work and related work indices continuously throughout the test. Breath-by-breath gas sampling and analysis were recorded continuously through a turbine flow meter and a gas sampling line connected to a cardiopulmonary metabolic system (Cosmed Quark b[2], Rome, Italy). Heart rate (HR) was measured by means of telemetry (Polar, Polar Electro Oy, Finland) and integrated with the metabolic system. The gas analysers and turbine flow meter were calibrated prior to each test. Whole blood lactate concentrations were measured with an automated blood lactate meter (Lactate Pro, Arkray Inc., Kyoto, Japan), before exercise, at termination of the test and after each workload until a lactate concentration of 4 $mmol.l^{-1}$ or higher was registered.

Subjects warmed up on the kayak ergometer for 5 minutes at 50% of their perceived maximum effort. The exercise test commenced at an initial workload of 75 W and the workload was increased by 25 W every 3 minutes until the blood lactate concentration reached 4 $mmol.l^{-1}$ or more. A 30-second rest period followed each 3-minute interval for blood sampling. After the subject reached 4 $mmol.l^{-1}$, the workload was increased by 25 W every 2 minutes, with no rest breaks, until the subject reached exhaustion. On the K1 Ergo, power output is a function of the force exerted during each stroke and the stroke rate. The paddler was therefore instructed to manually maintain the predetermined power output (reflected on the kayak monitor) by increasing his stroke rate and/or the force exerted during each stroke. Subjects were considered exhausted if they could not sustain the specific workload for 15 seconds or if they could not reach the new workload within 15 seconds. No subject completed fewer than 6 workloads or more than 10 workloads. The averages of the highest, consecutive 10-second values for VO_2, HR and VE during the incremental test were calculated as the maximum values.

VT was detected through specialised computer software analysis, using one of the methods introduced by Wasserman *et al.*[17] VT was defined as the point where a non-linear increase in VE occurred when plotted against VO_2, expressed as a percentage of $VO2_{max}$ (%VO_{2max}). LT was subjectively detected, as the PO corresponding to a blood lactate concentration of 4 mmol.l^{-1}. The average of the highest consecutive 10-second VO_2 values at that specific PO was calculated as the LT, and expressed as a percentage of VO_{2max}.

Pulmonary function

Forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1) and peak expiratory flow rate (PEFR) were measured by means of a flow-volume curve. The spirometric variables were measured with a unit using a turbine flow meter for volume measurements and the Spirometry reader 2000 (Cosmed Quark b^2, Rome, Italy). Calculations were made with Spirometry PC software according to the spirometry standards of the American Thoracic Society (ATS) and the European Respiratory Society (ERS). Each subject performed the manoeuvres while seated on a chair and wearing a nose clip. The subject had to seal his mouth around a carton mouthpiece connected to the flow meter, take 3 normal breaths, then inhale to total lung capacity (TLC) and immediately exhale maximally, as rapidly and as forcefully as possible. Each subject performed a minimum of 3 and a maximum of 8 manoeuvres. At least 2 flow-volume curves, in which the FVC and FEV_1 did not differ by more than 5%, were required from each subject. The curve with the greatest sum of FVC and FEV_1 was selected as the final measurement.

Maximum voluntary ventilation (MVV) in 12 seconds was measured to assess respiratory muscle endurance. The subject was instructed to inhale and exhale through the mouthpiece as maximally and as rapidly as possible for 12 seconds. At least 3 efforts were registered and the best measurement of 2 (within 5% variance) was recorded. Ventilated air was measured in litres per minute (l.min^{-1}).

Ethics

This study was approved by the Ethics Committee of Stellenbosch University (Project number 2003/024/N).

Statistics

Descriptive statistics were presented as mean ± SD and 95% confidence intervals. Unpaired Student's t-tests were used to detect significant differences in the measured variables between the elite and sub-elite paddlers. The outcome variables from this study were compared with the published data of Van Someren and Palmer[15] using the independent Student's *t*-test for mean values.

TABLE I. Kinanthropometric characteristics (mean ± SD and 95% CI for the difference) of elite and sub-elite endurance paddlers

Variable	Elite paddlers (*N* = 11) (Mean ± SD)	Sub-elite paddlers (*N* = 9) (Mean ± SD)	95% CI for the difference between means
Age (yrs)	26 ± 6	31 ± 7	-11.1 - 1.1
Weight (kg)	78.6 ± 6.9	81.9 ± 6.9	-9.8 - 3.2
Stature (cm)	182.7 ± 7.2	186.3 ± 6.3	-10.0 - 2.8
Sitting height (cm)	97.9 ± 3.1	97.8 ± 4.5	-3.5 - 3.7
Sitting height as % of stature	53.6 ± 0.9 *	52.5 ± 1.2	0.1 - 2.1
Arm length (cm)	81.9 ± 3.8	83.7 ± 2.8	-5.0 - 1.4
Arm span (cm)	190.5 ± 9.0	195.8 ± 8.6	-13.6 - 3.0
Sum of 6 skinfolds (mm)	63.2 ± 18.4	58.3 ± 9.9	-9.5 - 19.3
Body fat (%) †	11.6 ± 3.5	11.1 ± 1.5	-2.1 - 3.1
Girths (cm)			
Upper arm (relaxed)	32.6 ± 2.0	32.8 ± 1.6	-1.9 - 1.5
Upper arm (tensed)	34.5 ± 1.8	34.4 ± 1.4	-1.4 - 1.6
Forearm	28.6 ± 1.0	29.0 ± 1.0	-1.3 - 0.5
Chest	104.5 ± 6.0	107.6 ± 6.2	-8.9 - 2.7
Calf	36.2 ± 2.0	35.0 ± 5.2	-2.4 - 4.8
Humerus breadth (cm)	7.2 ± 0.5	7.0 ± 0.5	-0.3 - 0.7
Femur breadth (cm)	9.9 ± 0.3	10.0 ± 0.7	-0.6 - 0.4
Somatotype			
Endomorphy	2.4 ± 0.8	2.4 ± 0.6	-0.7 - 0.7
Mesomorphy	4.7 ± 1.0	3.9 ± 1.4	-0.3 - 1.9
Ectomorphy	2.6 ± 0.7	2.9 ± 0.7	-0.9 - 0.4

Four skinfolds: ∑ (biceps + triceps + subscapular + suprailiac).
* Significantly greater than that of the sub-elite paddlers, $p < 0.05$.
† Body fat % was calculated from the sum of 6 skinfolds using the equation of Withers *et al.*[18]
CI= confidence interval.

TABLE II. Cardiorespiratory characteristics (mean ± SD and 95% CI for the difference) of the elite and sub-elite endurance paddlers

Variable	Elite paddlers (N = 11) (Mean ± SD)	Sub-elite paddlers (N = 9) (Mean ± SD)	95% CI for the difference between means
VO_{2max} ($l.min^{-1}$)	4.4 ± 0.3	4.1 ± 0.5	-0.1 - 0.7
VO_{2max} ($ml.kg^{-1}.min^{-1}$)	55.6 ± 7.0 *	49.6 ± 5.6	0.1 - 12.1
HR_{max} (bpm)	180 ± 8	181 ± 10	-9.5 - 7.5
VE_{max} ($l.min^{-1}$)	156 ± 20	151 ± 20	-13.9 - 23.9
PPO (W)	286 ± 23 *	261 ± 27	1.5 - 48.5
PPO: Weight ($W.kg^{-1}$)	3.7 ± 0.4†	3.2 ± 0.2	0.2 - 0.8
Time to exhaustion (sec)	1619 ± 287 *	1355 ± 263	2.8 - 525.2
Ventilatory threshold (VT) as % VO_{2max}	72.3 ± 4.7	72.8 ± 6.2	-5.6 - 4.6
PO at VT	192 ± 49.8	172 ± 33.4	-20.9 - 60.9
Lactate threshold (LT) as % VO_{2max}	82.9 ± 6.8	79.8 ± 7.8	-3.8 - 10.0
PO at LT	225 ± 34.7	195 ± 36.9	-3.7 - 63.7

* Significantly greater than that of the sub-elite paddlers, $p < 0.05$.
† Significantly greater than that of the sub-elite paddlers, $p < 0.01$.
CI= confidence interval.

Results

Kinanthropometry

Table I presents the mean kinanthropometric variables for the elite and sub-elite paddlers. There were no significant differences between the 2 groups for most of the kinanthropometric variables, except sitting height as a percentage of stature. The elite paddlers had a significantly greater sitting height (2%) than the sub-elite paddlers ($p < 0.05$).

There were no significant differences in somatotype scores between the elite and sub-elite paddlers. Overall, the paddlers in this study can be described as balanced mesomorphs. This indicates that they had a body shape characterised by large muscle mass with broad bone diameter relative to their stature.

Incremental exercise test

Table II presents the cardiorespiratory responses during the incremental exercise testing of the elite and sub-elite paddlers, respectively. The elite paddlers showed statistically significantly greater values for relative VO_{2max} ($p < 0.05$), PPO ($p < 0.05$) and PPO to weight ratio ($p < 0.01$) than the sub-elite paddlers. There were no significant differences in absolute VO_{2max}, HR_{max}, VE_{max}, LT or VT between the elite and sub-elite paddlers.

Pulmonary function

There were no significant differences in FVC, FEV_1 and PEF between the 2 groups. The elite paddlers had a significantly greater MVV (12%, $p < 0.05$) than the sub-elite paddlers.

Discussion

Due to a lack of studies on kayak endurance paddlers most results in the present study were compared with results from studies on kayak sprint paddlers. Sprint and endurance events have very different physical and physiological requirements, therefore contradictory outcomes between the present study and previous studies were expected. In general, the differences between sprint and endurance events are known for other sports, particularly cycling and running. Comparisons between this study (endurance paddlers) and previous studies (sprint paddlers) are not only unique in a South African context, but are particularly novel for kayaking.

Kinanthropometric profile

Sitting height relative to stature was significantly greater in the elite paddlers than the sub-elite paddlers (Table I). This finding is in agreement with the findings of Fry and Morton,[3] who reported that selected sprint and endurance provincial paddlers had significantly greater values for sitting height than non-selected provincial paddlers. Cermak *et al.*[2] also found that the sitting height of paddlers (N = 17) was 3.4% greater than the sitting height of non-paddlers (N = 72). Only Van Someren and Palmer[15] found no significant differences in sitting height between international and national-level sprint paddlers. The possible answer to the different outcomes may lie in the type of paddlers included in the studies. Only Van Someren and Palmer[15] studied exclusively sprint paddlers (200 m). The other studies involved mixed groups of both sprint and endurance paddlers (500 m - 42 km), and the present study was limited to endurance paddlers. It seems, therefore, that sitting height may be a contributing factor to success in kayak endurance events, but less so in kayak sprint events. The reason for this finding is not obvious.

A major finding in the literature is that successful paddlers exhibit larger upper-body characteristics than less successful paddlers.[3,15] This finding is also consistent with other studies reporting the characteristics of elite sprint paddlers (500 m and 1 000 m).[2,8,12,14] It is therefore clear that paddlers competing over sprint distances require greater upper-body muscularity for kayak success. However, in this study no differences were found in upper-body characteristics (except for sitting height relative to stature) between the elite and sub-elite endurance paddlers. It seems therefore that upper-body muscularity is less important for top-level kayak endurance performance (10 km and 42 km).

The kinanthropometric profile of the paddlers in the present study was compared with that of the sprint paddlers of Van Someren and Palmer[15] to determine to what extent local endurance paddlers physically resemble international sprint paddlers. The study by Van Someren and Palmer[15] was selected as the comparative study because at the time it constituted the most recent data available in the literature, and the authors measured similar parameters to those in the present study. Comparative statistics are presented in Table III.

Compared with the international sprint paddlers of Van Someren and Palmer,[15] the elite endurance paddlers showed significantly lower scores for body weight, humerus breadth tensed upper arm girth, and calf girth. There were no differences in standing height between the elite sprinters and the elite endurance paddlers. However, compared with the national-level sprint paddlers of Van Someren and Palmer,[15] the elite endurance paddlers had significantly greater scores for sitting height (98 ± 3.1 v. 94.4 ± 2.6 cm, $p < 0.05$) and relaxed upper-arm girth (33 ± 2 v. 30.4 ± 1.9 cm, $p < 0.05$). Therefore, with regard to body size, the elite endurance paddlers in the present study had physical characteristics different from those of the international sprint paddlers of Van Someren and Palmer,[15] but they had more or less the same kinanthropometric profile as the less successful (national) sprint paddlers. A possible reason for the differences is that sprint events require great power, and therefore greater upper-body muscularity, whereas this requirement is less important for paddlers in kayak endurance events. In fact, it would be advantageous for endurance paddlers to be lean and similar in build to endurance runners.

The elite paddlers in this study had a balanced mesomorph somatotype classification. This is in accordance with the results of Van Someren and Palmer.[15] Therefore, despite some differences in body size, it seems that endurance paddlers and sprint paddlers overall have the same somatotype (body build).

Cardiorespiratory responses

The successful paddlers in this study had significantly higher values for relative VO_{2max}, PPO and PPO to weight ratio compared with the less successful paddlers (Table II). These differences in the outcome variables of incremental exercise testing are partly supported by the findings of Fry and Morton,[3] although they found differences in absolute VO_{2max} and time to exhaustion between successful and less successful paddlers. In contrast to these findings Van Someren and Palmer[15] found no significant differences in any of the maximum aerobic capacity variables between their successful and less successful sprint paddlers. In both studies[3,15] PPO to weight ratios were not reported and Fry and Morton[3] also did not report PPO during incremental testing.

From the above 2 studies one can conclude that the results for maximum aerobic capacity are not important factors in distinguishing between successful and less successful paddlers in kayak sprint events. The fact that Fry and Morton[3] found significant differences can be explained by the fact that their paddlers were successful over both sprint and endurance distances (i.e. a mixed group). Their sample therefore included paddlers with a wider range of abilities (7 selected state paddlers and 31 non-selected state paddlers). However, in the assessment of endurance paddlers exclusively, the results of maximum aerobic capacity are probably an important discriminating factor between successful and less successful endurance paddlers.

One must, however, consider the fact that the different results could be explained by the differences in the test protocols and types of apparatus used to achieve maximum aerobic

TABLE III. Comparison between South African (SA) elite endurance paddlers and UK elite sprint paddlers

Variable	SA endurance paddlers (N = 11) (Mean ± SD)	UK sprint paddlers (N = 13) (Mean ± SD)	95% CI for differences in mean values
Age (yrs)	26 ± 6	31 ± 7	-10.6 - 5.8
Weight (kg)	78.6 ± 6.9	81.9 ± 6.9	-9.2 - 2.6
Stature (cm)	182.7 ± 7.2	186.3 ± 6.3	-9.3 - 2.1
Sitting height (cm)	97.9 ± 3.1	97.8 ± 4.5	-3.2 - 4.5
Girths (cm)			
Upper arm (relaxed)	32.6 ± 2.0	32.8 ± 1.6	-1.7 - 1.3
Upper arm (tensed)	34.5 ± 1.8	34.4 ± 1.4	-1.3 - 1.5
Forearm	28.6 ± 1.0	29.0 ± 1.0	-1.3 - 0.5
Chest	104.5 ± 6.0	107.6 ± 6.2	-8.3 - 2.1
FVC (l)	6.8 ± 0.9	6.3 ± 0.7	-0.2 - 1.2
VO_{2max} (l.min^{-1})	4.4 ± 0.3	4.5 ± 0.6	-0.5 - 0.3
VO_{2max} (ml.kg-1.min^{-1})	55.6 ± 7.0	52.6 ± 4.9	-2.1 - 8.1
HR_{max} (bpm)	180 ± 8 *	190 ± 12	-18.8 - -1.2

* Statistically significant difference, $p < 0.05$.
CI= confidence interval.

capacity. All 3 studies used different exercise protocols, while Fry and Morton[3] did not use the K1 Ergo but a modified cycle ergometer mounted on a kayak frame.

The cardiorespiratory characteristics of the elite endurance paddlers were compared with the international and national-level sprint paddlers of Van Someren and Palmer[15] in order to rate the local paddlers in terms of their cardiorespiratory fitness. The elite South African endurance paddlers reached significantly lower HR_{max} values (180 ± 8 v. 190 ± 12 beats per minute (bpm), $p < 0.05$), but higher PPO values (286 ± 23 v. 250 ± 27 W, $p < 0.05$) compared with both the international and national-level sprint paddlers of Van Someren and Palmer.[15] This can probably be attributed to the different test protocols used in the 2 studies. There were no statistically significant differences in either absolute or relative VO_{2max} between the elite endurance and elite sprint paddlers. Overall, the South African endurance paddlers compared well with the international sprint paddlers in terms of their maximum aerobic capacities.

Pulmonary function

MVV was the only pulmonary function variable that significantly differentiated between the elite and the sub-elite endurance paddlers (220 ± 16.7 v. 182 ± 39.7 $l.min^{-1}$, $p < 0.05$). A possible explanation for this difference is that the higher frequency of aerobic training of the elite paddlers probably improved their respiratory muscle endurance more than that of the sub-elite paddlers. Evidence that aerobic training can improve MVV was reported by Robinson and Kjelgaard.[11] They found that sedentary males significantly improved their MVV by 13.6% ($p < 0.01$) after following a 20-week walk/run training programme.

In accordance with the findings of Van Someren and Palmer,[15] there was no significant difference in FVC (Table IV) between the elite and sub-elite endurance paddlers in this study. Fry and Morton,[3] however, found a significantly higher FVC in selected provincial paddlers compared with non-selected provincial paddlers. This finding can probably be attributed to the significant difference in stature between their 2 groups (180 ± 5 v. 175 ± 5 cm, $p < 0.05$). It seems therefore that lung capacity, measured as FVC, is a less important variable in distinguishing between successful and less successful endurance paddlers.

The elite endurance paddlers in this study had similar lung capacities (FVC 6.8 ± 0.9 v. 6.3 ± 0.9 l, $p > 0.05$) to the international sprint paddlers of Someren and Palmer[15] and superior lung capacities (FVC 6.8 ± 0.9 v. 6.0 ± 0.6 l, $p < 0.05$) compared with their national-level sprint paddlers. The local paddlers also showed superior values for pulmonary function compared with competitive paddlers from other studies.[3,8,12] It is possible that the differences in lung capacity are due to differences in stature, with the South African endurance paddlers being taller than most other paddlers reported on in the literature. Since stature is one of the most important determinants of lung function, this would be a logical explanation. On the other hand it is possible that the superior lung function of the elite South African endurance paddlers can be attributed to the effects of long-term endurance training. The positive effects of regular endurance training are supported in the literature where significantly greater lung capacities were observed for athletes compared with sedentary individuals.[1,6,7,10] Significant increases in FVC have been found after a 20-week walk-run training programme (40 minutes per day, 3 times per week) in 12 previously sedentary individuals[11] and after 6 - 8 months of regular training in 9 adolescent rowers compared with 13 controls.[1]

We acknowledge the fact that all aspects related to kayak river racing cannot be tested in the laboratory. The level of skill and knowledge of specific river conditions cannot be accounted for, or simulated, in laboratory tests. Further, the physical and physiological characteristics of multi-day river races may not be the same as those required for international flat-water marathon racing. The results of the current study should therefore be interpreted with these limitations in mind. Nevertheless, we are of the opinion that our results provide valuable baseline data for further studies on kayaking.

Conclusion

Of the 3 basic assessments (kinanthropometry, incremental exercise testing and pulmonary assessments), sitting height as a function of stature, relative VO_{2max}, absolute and relative PPO, time to exhaustion and MVV revealed significant differences between the elite and sub-elite endurance paddlers. It seems that the incremental test on the K1 ergometer is a useful test to differentiate between those attributes essential for success in kayak endurance events. Sitting height as a percentage of stature was the only kinanthropometric variable that significantly differentiated successful from less successful paddlers. This finding suggests that the anthropometry of kayak endurance paddlers is not that important in identifying paddlers for kayak endurance suc-

TABLE IV. Pulmonary function variables (mean ± SD and 95% CI of the elite and the sub-elite endurance paddlers

Variable	Elite paddlers (*N* = 11) (Mean ± SD)	Sub-elite paddlers (*N* = 9) (Mean ± SD)	95% CI for the difference between means
FVC (l)	6.8 ± 0.9	6.8 ± 1.0	-0.9 - 0.9
FEV_1 (l)	5.4 ± 0.5	5.4 ± 0.8	-0.6 - 0.6
PEF ($l.s^{-1}$)	11.8 ± 1.7	11.3 ± 2.2	-1.3 - 2.3
MVV ($l.min^{-1}$)	220.3 ± 16.7 *	182.2 ± 39.7	10.5 - 65.7

* Significantly greater than that of the sub-elite paddlers, $p < 0.05$.
CI= confidence interval.

cess. The pulmonary function test results showed that the MVV test can be recognised as a significant test to identify kayak endurance success.

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