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ORIGINAL ARTICLE

Physiological factors to predict on traditional rowing performance

Mikel Izquierdo-Gabarren · Rafael González de Txabarri Expósito · Eduardo Sáez Sáez de Villarreal · Mikel Izquierdo

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Abstract The purpose of this study was to determine the best prediction factors of traditional rowing performance in traditional elite (ER) and amateur (AR) rowers. Average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$), average power output which elicited a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ \mathrm{mmol\ l^{-1}}}$), power output in 10 maximal strokes ($W_{10\ \mathrm{strokes}}$), maximal strength and muscle power output during a bench pull (BP) and anthropometric values were all measured for 46 trained male rowers aged 21–30 with 8–15 years of rowing training experience. The ER group showed greater body mass (5%, $p < 0.05$), greater fat free body mass (5%, $p < 0.05$), greater $1RM_{BP}$ (13%, $p < 0.001$), longer training experience (43%, $p < 0.001$), and a shorter time in the 2,000 m test (4%, $p < 0.05$) than the AR group. The ER group showed higher power output values in $W_{10\ \mathrm{strokes}}$ (9%, $p < 0.01$), $W_{20\ \mathrm{min}}$ (15.4%, $p < 0.01$) and $W_{4\ \mathrm{mmol\ l^{-1}}}$ (17.8%, $p < 0.01$) compared with the AR group. Significant relationships were observed between $W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$ ($r = 0.65$ and 0.80; $p < 0.01$ in ER and AR, respectively). The indices for rowing performance suggested that $W_{20\ \mathrm{min}}$, $W_{4\ \mathrm{mmol\ l^{-1}}}$, $W_{10\ \mathrm{strokes}}$ and $1RM_{BP}$ were the most important predictors of traditional rowing performance in elite and amateur rowers.

Keywords Traditional rowing · Maximal strength · Muscle power · Bench pull · Anaerobic threshold

Introduction

There are two different rowing techniques: traditional and Olympic rowing. Competitive Olympic rowing is the oldest modern organised sport, which includes events with different types of boats and number of crewmembers (i.e. single, double or quad sculls and paired four- or eight-oared boats). Traditional rowing competition (i.e. with fixed-seat rowing) is a type of rowing performed on the sea, manned by 13 rowers and a cox. The distinguishing feature of these boats is that they are suitable for rowing in heavy seas thanks to the *palka* or "false bows", a sock-like breakwater which is fitted over the bow (Volianitis and Secher 2007). Some important differences between the two rowing types are distance, mean time and velocity of the boat, total number of strokes, or mean force and power per stroke (Table 1).

Competitive Olympic rowing is regarded as an endurance sport and there is a close relationship between rowing performance and rowers' aerobic capacity (Cosgrove et al. 1999; Kramer et al. 1994; Yoshiga and Higuchi 2003). Rowing performance is dependent upon the functional capacity of both aerobic and anaerobic energy pathways (Secher 1973), with the amount of energy derived from anaerobic metabolism amounting to 21–30% (Secher 1993), and 70–86% from aerobic metabolism (Messonnier et al. 1997).

Olympic rowing performance, as measured on water, not only depends on physiological characteristics but also on mechanicals or external factors, including environmental conditions. Rowing ergometers have improved training and provided a controllable and repeatable tool to

M. Izquierdo-Gabarren · R. G. de Txabarri Expósito
Research Center of Rowing Club Orio, Orio, Spain

E. S. S. de Villarreal
Department of Computer Sciences and Sports,
University Pablo de Olavide, Sevilla, Spain

M. Izquierdo (✉)
Research, Studies and Sport Medicine Center,
Government of Navarra, C/Sangüesa 34,
31005 Pamplona, Navarra, Spain
e-mail: mikel.izquierdo@ceimd.org

Table 1 Differences between the two rowing modalities

	Olympic rowing	Traditional rowing[b]
Distance (m)	2,000 m	5,556 m
Mean time (min)	5.5–7	19–20
No. of rowers in the boat	2, 4 or 8	13
Categories	Heavyweight and Lightweight	No categories
Length of boat	Variable	Unique
Mean velocity of the boat (m/seg)	5.3–6.0[a]	4.5–4.7
Laps	No	3
Stroke per minute	32–38[a]	35–40
Total number of strokes	210–230[a]	675–725
Mean force per stroke (N)	500–700[a]	400–600
Mean power per stroke (J)	450–550[a]	250–350
Regatta field	Flat waters	Out to sea
Muscular participation	Upper extremity + Lower extremity	Upper extremity, less implication of lower extremity

[a] Steinacker et al. (1998)

[b] Data not published

use in the assessment of Olympic rowing performance. Numerous studies have tried to define performance factors in the 2,000 m ergometer (Bourdin et al. 2004; Cosgrove et al. 1999; Ingham et al. 2002; Jurimae et al. 1999; Perkins and Pivarnik 2003; Riechman et al. 2002; Russell et al. 1998). In these studies, rowers of different levels and boats were utilised, and different predictors of performance were frequently obtained, such as VO_{2max} (Secher 1993), percentage of slow twitch fibres (Roth et al. 1983), body mass (Secher 1993), power output at a blood lactate concentration ($[La^-]_b$) of 4 mmol l^{-1} (Roth et al. 1983) or peak power output (Ppeak) sustained during maximal incremental testing (Bourdin et al. 2004). The majority of these studies defined the maximum consumption of oxygen (VO_{2max}) and the maximum aerobic power as best predictors, accounting for 49–81% of Olympic rowing performance variance (Cosgrove et al. 1999; Ingham et al. 2002; Kramer et al. 1994). In a group of highly trained Olympic rowers, Bourdin et al. (2004) reported that multiple regression analysis taking into account Ppeak sustained during maximal incremental testing, body mass, maximal oxygen uptake, oxygen consumption corresponding to a blood lactate of 4 mmol l^{-1} expressed in percentage of VO_{2max}, and rowing gross efficiency (RGE) explained 82.8% of rowing ergometer performance over 2,000 m.

Several studies have also emphasised the important role of factors such as maximal strength and muscle power output in Olympic rowing performance (Secher 1993; Steinacker et al. 1986). As a typical power-endurance sport, rowers need physical strength to achieve high power per stroke, endurance to sustain this power, as well as specific motor and tactical skills (Secher 1993; Steinacker et al. 1986). The power produced by the rower at the handle is a decisive factor in performance (Baudouin and Hawkins 2002). Ingham et al. (2002) determined that maximal force (F_{max}) and maximal power (W_{max}) production were the strongest correlates ($r = 0.95$) of measured performance. Owen et al. (2002) demonstrated that heavyweight athletes were able to produce greater W_{max} and F_{max} compared to lightweight athletes. Steinacker et al. (1998), and Fiskerstrand and Seiler (2004) considered that strength training in rowers' teams has increased approximately 20% in the last few years, suggesting that greater intensity in training may be more influential in performance. To our knowledge, however, no studies have compared current anthropometric and physiological profiles of male traditional rowers. Examination of fitness profiles in rowers can contribute to talent selection and identification and could be of great importance for optimal construction of strength/power and endurance training programs to improve rowing performance.

Based on evidence that optimised Olympic rowing performance depend on both endurance and strength conditions one may hypothesise that a difference exists between amateur and elite rowers regarding absolute anthropometric characteristics, maximal strength, muscle power output as well as several indices of endurance rowing performance. Second, some anthropometric, strength and muscle power values could be related to Olympic rowing performance. Therefore, the aim of the present study was to examine which one of the performance factors: average power during the 20-min all-out test ($W_{20\ min}$), average power output which elicited a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ mmol\ l^{-1}}$), power output in 10 maximal strokes ($W_{10\ strokes}$), maximal strength and muscle power output during a bench pull (BP), or anthropometric values would be able to differentiate rowers at different standards in traditional rowing. A secondary purpose was to determine the best predictors of traditional rowing performance.

Materials and methods

Experimental design and approach to the problem

This study was designed to determine differences in physical fitness, anthropometric and rowing performance between elite and amateurs rowers. The two groups of rowers were tested and compared to determine whether variables in rowing performance [i.e. average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$), average power output which elicited a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ \mathrm{mmol\ l^{-1}}}$), power output in 10 maximal strokes ($W_{10\ \mathrm{strokes}}$) on an ergometer (Concept II system, model D, Morrisville, VT, USA)]; physical fitness (maximal strength, muscle power-load curve and maximal number of repetitions leading to failures with 75% of 1RM during a bench pull) and anthropometric variables were a distinguishing feature of either group. If differences existed, then this would tend to indicate their relative importance as parameters affecting progress towards the elite professional class.

This study was carried out in March, at the end of the specific preparatory period. During the months preceding the beginning of the study, the subjects had been training six times a week on average, with a training session of 120 min duration. The share-out of training was similar to that of Olympic rowing (Maestu et al. 2005) with 60% of the specific training done in water, 20% of strength training in the gym and 20% athletic training. During the 5 months preceding the beginning of the study, the subjects took part in a resistance training program, consisting mainly of typical (free weight) weight lifting exercises (i.e. including bench press, bench pull, and back squat exercises) for 5 sets of 10–15 repetitions, with a relative intensity of 50–85% of 1RM.

Subjects

This study involved a group of 46 trained male rowers aged 21–30 with 5–10 years of resistance training experience and 8–15 years of rowing training experience (Table 2). Two teams of different levels from the same rowing club took part in the study. The subjects were divided into two groups depending on their competition standard: either elite rowing team (ER; $n = 24$) or amateur rowing team (AR; $n = 22$). The ER team participated in the ACT league (top category in Spanish traditional rowing league) while AR participated in the ARC1 league (second division Spanish traditional rowing league). The ER team was the current Spanish Olympic rowing championship team in an eight-oared boat. Before inclusion in the study, all subjects were medically screened and were seen to be free from any orthopaedic, cardiac, endocrinal or medical problems that would rule out their participation or influence the results of the research. Each participant gave his written, informed consent to participate after the risks of the research were carefully explained. The study was conducted in line with the stipulations of the Declaration of Helsinki and was approved by the Ethics Committee of the department concerned.

Physical characteristics

The anthropometric variables of height (m), body mass (kg), body fat (%) and fat free body mass (kg) were measured for each subject. Height and body mass were measured using a self-calibrated platform (Año Sayol, Barcelona, Spain) recorded to the nearest centimetre and measured to the nearest 0.01 kg, respectively. Whole-body fat was estimated according to the skinfold thickness method developed by Pollock and Jackson (1984). Skinfold measurements were taken from seven sites: at the subscapular, tricipital, midaxillary, suprailiac, pectoral, abdominal, and anterior thigh levels using a Harpenden skinfold caliper. A minimum of two measurements were made at each skinfold site by the same highly experienced investigator for each measurement. Fat free body mass (FFM, in kg) was calculated as the difference between body mass and body fat.

Testing procedures

All rowers were carefully familiarised with the testing protocol, as they had been previously tested on several occasions in previous seasons for training prescription purposes. Furthermore, several warm-up muscle actions were recorded prior to the actual maximal, explosive and endurance test actions.

The study consisted of a 2-week testing period with a randomised, balanced design. During this time, subjects were required to report to the laboratory on five separate occasions within a 2-week period. The testing time was constant throughout the study. During the first week, subjects visited the laboratory on three different days (Monday–Wednesday–Friday) as a part of a regular testing program. On day 1 and 2, each participant was tested for maximal strength, muscle power output and maximal number of repetitions before failure during bench pull. On the third testing day, the anthropometric variables (height, body mass, and percentage of body fat) and power output in

Table 2 Physical characteristics, training experience and results in different test of performance in bench pull and rowing ergometer in elite rowers group (ER), amateur rowers group (AR) and in a combination group (ER + AR)

	ER ($n = 24$)	AR ($n = 22$)	Combination group (ER + AR)
Age (years)	28 ± 5**	23 ± 4	25.6 ± 5
Height (cm)	182 ± 3	182.1 ± 6	182 ± 5
Body mass (kg)	84.2 ± 5*	80.2 ± 7	82.3 ± 7
Body fat (%)	12.3 ± 1	12.2 ± 1	12.2 ± 1
Fat free body mass (kg)	73.7 ± 4*	70.3 ± 6	72.1 ± 5
Training experience (years)	15.2 ± 4**	8.3 ± 2	11.9 ± 5
Time in 2,000 m (s)	376 ± 8.36*	394 ± 12.34	386 ± 10.47
$1RM_{BP}$ (kg)	102.45 ± 7**	90.63 ± 11	96.8 ± 11
$W_{BP15\%}$ (W)	288.44 ± 33	269.94 ± 43	279.59 ± 39
$W_{BP30\%}$ (W)	465.87 ± 48*	429.93 ± 60	448.68 ± 56
$W_{BP45\%}$ (W)	601.45 ± 56**	544.93 ± 71	574.42 ± 69
$W_{BP60\%}$ (W)	653.65 ± 48**	587.61 ± 90	622.06 ± 78
$W_{BP75\%}$ (W)	668.66 ± 65**	598.31 ± 78	635.02 ± 79
$W_{BP85\%}$ (W)	609.62 ± 70*	572.66 ± 74	591.95 ± 74
$W_{BP100\%}$ (W)	494.91 ± 67**	436.58 ± 51	467.01 ± 66
W_{maxBP} (W)	682.4 ± 55*	609.92 ± 82	647.73 ± 78
$W_{indexBP}$ (W)	3782.63 ± 307*	3440 ± 410	3618.76 ± 395
Rep_{maxBP}	13.04 ± 3*	10.9 ± 3	12.02 ± 3
$Rep75_{sumBP}$ (W)	6975.63 ± 914**	5122.87 ± 832	6049.25 ± 1275
$W_{10\ strokes}$(W)	629.5 ± 45**	567.9 ± 87	600.08 ± 74
$W_{4\ mmol\ l^{-1}}$ (W)	273.4 ± 22***	232.1 ± 31	253.2 ± 34
$W_{20\ min}$ (W)	290.8 ± 18***	251.8 ± 29	272.69 ± 30

Significant difference (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$) compared to amateur rowers. Results are mean ± SD

One repetition maximum in bench pull ($1RM_{BP}$); Power-load relationship of the upper extremity muscles in bench-pull position, using the relative loads of 15, 30, 45, 60, 75, 85 and 100% of 1RM bench-pull exercise ($W_{BP15\%}$–$W_{BP100\%}$). Maximal power from all loads in bench pull (W_{maxBP}); Power output index in bench pull ($W_{indexBP}$); Power at different loads of 1RM in bench pull ($W_{BP100\%}$–$W_{BP15\%}$); Maximum number of repetitions leading to failure in bench pull (Rep_{maxBP}); Sum of power output of repetitions leading to failure at submaximal load to 75% of 1RM during bench pull ($Rep75_{sumBP}$); mean power of ten strokes ($W_{10\ strokes}$); mean power output which elicited a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ mmol\ l^{-1}}$); mean power during 20-min all-out test ($W_{20\ min}$)

ten maximal strokes ($W_{10\ strokes}$) were measured. During this week, two endurance sessions were performed at low intensity (blood lactate concentration below 2 mmol l^{-1}). During the second week, participants visited the lab on two different occasions. During the first testing session, a progressive endurance test on the ergometer was completed. In the second testing session, a 20-min all-out test on a rowing ergometer was also measured ($W_{20\ min}$). The testing days were interspersed with rest periods of a minimum of 48 h to limit the effects of fatigue on subsequent tests. The subjects were instructed to avoid any strenuous physical activity during the duration of the experiment and to maintain their dietary habits for the entire duration of the study.

Maximal strength and muscle power tests

A detailed description of the maximal strength and muscle power testing procedure can be found elsewhere (Izquierdo et al. 2002). In brief, maximal strength of the upper extremity was assessed using one repetition maximum bench pull action ($1RM_{BP}$). Bench-pull (elbow and shoulder flexion) was chosen because it seems most specific to the rowing technique (McNeely 2000). Bilateral bench pull tests were completed with the use of standard bench pull equipment (Salter, Madrid, Spain) with the subjects adopting a position (lying face down on the bench with their arms completely stretched out and hands holding on to the bar), and with their weight suspended perpendicularly at 90°. A manual goniometer (Q-TEC Electronic Co. Ltd., Gyeonggi-do, Korea) was used at the elbow to standardise the range of motion. On command, the subjects performed a concentric arm flexion starting from the extended position to reach the full flexion (touching the bench) against the resistance determined by the weight. The warm-up consisted of a set of 10 repetitions with loads of 40–60% of the perceived maximum. Thereafter, five to six separate single attempts were made until the subject was unable to flex the arms to the required position. The last acceptable flexion with the highest possible load was determined as 1RM. The rest period between actions was always 2 min.

The power–load relationship of the upper extremity muscles was tested in bench-pull position, using the relative loads of 15, 30, 45, 60, 75, 85 and 100 of 1RM bench-pull exercise ($W_{\mathrm{BP}15\%} - W_{\mathrm{BP}100\%}$). On command, the subjects were instructed to move the loads as fast as possible. Two test actions were recorded and the best reading (with the highest power) was taken for further analysis. The rest period between each trial was 2 min.

Set of maximal power-output continuous repetitions until failure with submaximal load

During subsequent test sessions, each subject performed a maximal repetitive high power-output set until failure with a submaximal load corresponding to 75% of 1RM during bench pull. The maximum number of repetitions before failure in bench pull ($\mathrm{Rep}_{\mathrm{maxBP}}$) was calculated, plus the sum of power output of all repetitions at submaximal load to 75% of 1RM during bench pull ($Rep75_{\mathrm{sumBP}}$). Subjects were asked to move the bar as fast as possible during the concentric phase of each repetition until failure. Failure was defined as the time point when the bar ceased to move, if the subject paused more than 1 s when the arms were in the extended position, or if the subject was unable to reach the full flexion position of the arms. During the first repetitions, the cadence was controlled with a metronome with a frequency of 19 Hz. As fatigue increased and performance of repetitions became progressively more difficult, an individual rate of cadence less than 19 Hz was allowed, with the resting time between repetitions remaining constant.

During the upper extremity test actions, bar displacement, peak and mean power (Watts) were recorded by connecting a rotary encoder to the end part of the bar. The rotary encoder recorded the position and directions of the bar to an accuracy of 0.0003 m. Software (Fitrodyne, Fitronic, Bratislava, Slovakia) was used to calculate the power output for each repetition of bench-pull performed throughout the whole range of motion. The average power value obtained for each repetition was used to calculate the total average power produced during each set of repetitions until failure in both groups. For comparison purposes, an averaged index of muscle power output with all absolute loads examined was calculated in each group separately. Averaged index of muscle power in bench-pull position were calculated as the sum of the power values obtained under all experimental conditions for a given muscle group (W_{indexBP}). In addition, maximal power output was defined as the maximum power obtained from all loads examined (W_{maxBP}). The test–retest intraclass correlation coefficients for all anthropometric, strength and power variables were greater than 0.93 and the coefficients of variation (CV) ranged from 0.92 to 1.9%.

Rowing ergometer performance tests

The rowers were fully familiarised with the use of the wind-resistance braked rowing ergometer (Concept II, model D, Morrisville, VT, USA). All evaluations were performed on a modified ergometer with a drag factor of 145 and a static seat. The tests were accomplished with the legs in semi-flexion and the length adapted to each rower.

The maximal power recorded was the highest value displayed on the monitor of the ergometer when each subject rowed ten strokes with maximal effort ($W_{10\ \mathrm{strokes}}$) (Hartmann et al. 1993). The subjects warmed up for 15 min, finishing the warming up with some strokes at maximal power. They undertook two trials, followed by 5-min rest between trials. The best reading (with the highest power) was taken for further analysis.

Progressive ergometer tests were measured using an incremental step protocol, as defined by Ingham et al. (2002). The subjects warmed up for 10 min. The initial power was 150–180 W, depending on the rowers' body mass, increased by 25 W after each rest period. Heart rate (HR) was continuously recorded using a heart rate monitor (RS 800G3, Polar Electro, Finland). Blood samples were taken from the ear lobe during each rest period to measure lactate concentration ($[\mathrm{La}]_{\mathrm{b}}$). Blood lactate concentrations were measured with the Dr. Lange lactate analyser (Dr. Lange Miniphotometer Plus LP-20, Sports Package, Düsseldorf, Germany). Individual data points for the exercise blood lactate values were plotted as a continuous function against time. The exercise lactate curve was fitted with a second-degree polynomial function. The range of the individual correlation coefficient with the use of the mathematical function described above was $r = 0.98–0.99$ ($p < 0.001$). From the equation describing the exercise blood lactate curve, the stroke power associated with a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ \mathrm{mmol\ l}^{-1}}$) was interpolated. $W_{4\ \mathrm{mmol\ l}^{-1}}$ have been called the aerobic and anaerobic thresholds, respectively, by some researchers and have been shown to be important determinants of endurance performance capacity (Weltman 1995). Stroke frequency and subjective perception of the effort (Borg 20 scale) were also measured.

A 20-min all-out test was carried out after a 15-min warm-up. Based on the results of the previous progressive test, the intensity the rowers had to maintain was calculated as 250–350 W/stroke. The rowers covered an average distance of 5,000–6,300 m with 35–40 strokes/min and a total number of strokes of 675–725. The 20 min were carried out at maximum possible force, recording mean watts every 4 min, the average power at the end of the test, and the average power during the 20 min all-out test ($W_{20\ \mathrm{min}}$).

Statistical procedures

Standard statistical methods were used for the calculation of mean and standard deviations. Pearson product–movement correlation coefficients (r) were used to determine the association between average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$), average power output which elicited a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ \mathrm{mmol\ l^{-1}}}$), power output in 10 maximal strokes ($W_{10\ \mathrm{strokes}}$), maximal strength and muscle power output during a BP, and anthropometric characteristics. In addition, a stepwise multiple linear regression analysis was used to predict $W_{20\ \mathrm{min}}$. The independent variables ($W_{4\ \mathrm{mmol\ l^{-1}}}$, $W_{10\ \mathrm{strokes}}$, $1\mathrm{RM}_{\mathrm{BP}}$ and $\mathrm{Rep75}_{\mathrm{sumBP}}$) that correlated most significantly with $W_{20\ \mathrm{min}}$ were entered into stepwise procedure. The differences between the two groups for the aforementioned variables were determined using one-way analysis of variance (ANOVA), with Newman–Keuls post hoc comparisons. Statistical power calculations for t test correlation ranged from 0.71 to 0.95 in this study. The $P \leq 0.05$ criterion was used for establishing statistical significance.

Results

Physical characteristics and training experience

The ER group showed higher body mass (5%, $p < 0.05$), fat free body mass (5%, $p < 0.05$), age (21%, $p < 0.001$), training experience (43%, $p < 0.001$), and a shorter time in the 2,000 m test (4%, $p < 0.05$) than the AR group. There were no differences in body height and body fat percentage between the groups (Table 2).

Maximal strength, muscle power output and number of repetitions leading to failure

The $1\mathrm{RM}_{\mathrm{BP}}$ values of 102.45 ± 7.21 kg in ER were 13% greater ($p < 0.001$) than the 90.63 ± 11.08 kg recorded for AR. The shape of the average BP power-load curves in absolute values differed between groups (Table 2). At all loads examined (from 30 to 100% of 1RM, $p > 0.05$ at 15%), average power output and power output index were higher in ER group (from 6 to 13%; $p < 0.05$–0.01) than in AR. When muscle power output was expressed in relative kilograms of fat free body mass, the differences between the elite and the amateur group decreased.

The number of repetitions leading to failure in bench-pull performed with the optimal load that maximised power output was 19.3% higher in the ER group ($p < 0.05$) than in AR. Thus, the total power output of 6,975 ± 236 W produced during the bout of repetitions leading to failure at submaximal load to 75% of 1RM during bench pull in the ER group was 36.2% higher than in AR group (5,122 ± 214 J, $p < 0.001$) (Table 2).

Performance in rowing ergometer

On the rowing ergometer, the ER group exhibited higher power output values (Table 2) in ten maximal strokes (9% for $W_{10\ \mathrm{strokes}}$; $p < 0.001$), and in average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$) (15.4%; $p < 0.001$) compared with the AR group. During the progressive endurance test, the mean stroke power output that elicited a blood lactate concentration of 4 mmol l^{-1} was 17.8% higher ($p < 0.001$) in the ER than in the AR group (Table 2).

When the stroke power output that elicited a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ \mathrm{mmol\ l^{-1}}}$) and average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$) were expressed in relation to kilograms of body mass or fat free body mass, the differences between the elite and the amateur team disappeared at $W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$ or were reduced, as in the ten maximal strokes test ($W_{10\ \mathrm{strokes}}$).

Relationships between anthropometric characteristics and rowing performance

In both groups, the individual values of $W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$ correlated significantly with body mass and fat free body mass (from $r = 0.44$ to $r = 0.71$; $p < 0.05$–0.01) (Table 3). The relationship between the endurance rowers' index ($W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$), body mass and fat free body mass was also statistically significant when the rowers' group was taken as a whole (from $r = 0.53$ to $r = 0.58$; $p < 0.05$–0.01) (Table 3) (Fig. 1).

Relationships between strength, muscle power output and rowing performance

In the AR group, the individual values of $W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$ correlated positively with different strength and muscle power values (from $r = 0.43$ to $r = 0.71$; $p < 0.5$–0.01) (Table 3), whereas no significant relationships were observed in ER. The relationship between the endurance rowers' index ($W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$), maximal strength and various indices of muscle power output BP were also statistically significant when the rowers' group was taken as a whole (from $r = 0.29$ to $r = 0.73$; $p < 0.05$–0.01) (Table 3) (Fig. 2).

In both groups, the individual values of mean power output during ten maximal strokes ($W_{10\ \mathrm{strokes}}$) correlated

Table 3 Correlation coefficients between mean power output which elicited a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ \mathrm{mmol\ l^{-1}}}$) (A), mean power during 20-min all-out test ($W_{20\ \mathrm{min}}$) (B), and mean power of ten strokes ($W_{10\ \mathrm{strokes}}$) (C) and various anthropometric and physical fitness variables (maximal strength, maximal power of all loads in bench pull and muscle power index) in a Combination group (ER + AR) ($n = 46$)

	Height	Body mass	FFM	$1\mathrm{RM}_{\mathrm{BP}}$	W_{maxBP}	W_{indexBP}	$W_{4\ \mathrm{mmol\ l^{-1}}}$	$W_{20\ \mathrm{min}}$	$W_{10\ \mathrm{strokes}}$
Height	–	0.66**	0.67**	0.28	0.37	0.33	0.33	0.25	0.42*
Body mass	–	–	0.97**	0.62**	0.53**	0.55**	0.53**	0.65**	0.67**
FFM	–	–	–	0.66**	0.56**	0.57**	0.55**	0.66**	0.68**
$1\mathrm{RM}_{\mathrm{BP}}$	–	–	–	–	0.81**	0.85**	0.54**	0.62**	0.83**
W_{maxBP}	–	–	–	–	–	0.95**	0.51**	0.59**	0.81**
W_{indexBP}	–	–	–	–	–	–	0.47**	0.59**	0.83**
$W_{4\ \mathrm{mmol\ l^{-1}}}$	–	–	–	–	–	–	–	0.85**	0.51**
$W_{20\ \mathrm{min}}$	–	–	–	–	–	–	–	–	0.67**
$W_{10\ \mathrm{strokes}}$	–	–	–	–	–	–	–	–	–

Mean power output which elicited a blood lactate concentration of 4 mmol l^{-1} ($W_{4\ \mathrm{mmol\ l^{-1}}}$); Mean power during 20-min all-out test ($W_{20\ \mathrm{min}}$); Mean power of ten strokes ($W_{10\ \mathrm{strokes}}$); Fat free body mass (FFM); One repetition maximum in bench pull ($1\mathrm{RM}_{\mathrm{BP}}$); Maximal power of all loads in bench pull (W_{maxBP}); Power output index in bench pull (W_{indexBP})

* $P < 0.05$, ** $P < 0.01$

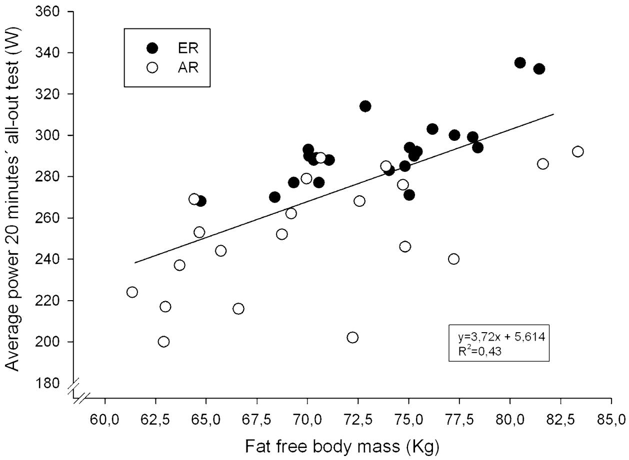

Fig. 1 The relationship between fat free body mass (kg) and average power during 20-min all-out test (W)

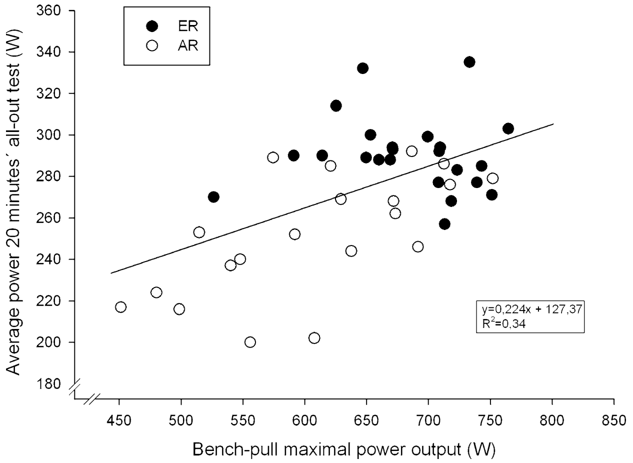

Fig. 2 The relationship between bench pull maximal power output (W) and average power during 20-min all-out test (W)

significantly with the individual values of $1\mathrm{RM}_{\mathrm{BP}}$ ($r = 0.55$ and 0.89; $p < 0.01$–0.001, respectively, for ER and AR groups) and the average index of muscle power output attained during bench-pull with different loads ($r = 0.52$ and 0.92; $p < 0.01$–0.001, respectively, for ER and AR groups) (Table 3).

Relationships between $W_{4\ \mathrm{mmol\ l^{-1}}}$, $W_{20\ \mathrm{min}}$ and mean power output during $W_{10\ \mathrm{strokes}}$

In both groups, significant relationship were observed between $W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$ ($r = 0.65$ and 0.80; $P < 0.01$ in ER and AR, respectively). The relationship between $W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$ was also statistically significant when the group was taken as a whole ($r = 0.85$; $p < 0.01$) (Table 3) (Fig. 3).

In the AR group, the individual values of mean power output during $W_{10\ \mathrm{strokes}}$ correlated positively with the individual values $W_{4\ \mathrm{mmol\ l^{-1}}}$ ($r = 0.50$; $p < 0.05$) and $W_{20\ \mathrm{min}}$ ($r = 0.72$; $p < 0.01$), whereas no significant relationships were observed in ER (Table 3) (Fig. 4).

The stepwise multiple linear regression analysis showed that $W_{4\ \mathrm{mmol\ l^{-1}}}$, $W_{10\ \mathrm{strokes}}$ and $Rep75_{\mathrm{sumBP}}$ accounted for 81% of the performance variance in average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$). In addition, $1\mathrm{RM}_{\mathrm{BP}}$ and $Rep75_{\mathrm{sumBP}}$ accounted for 38% of the performance variance when the dependent variable was $W_{4\ \mathrm{mmol\ l^{-1}}}$.

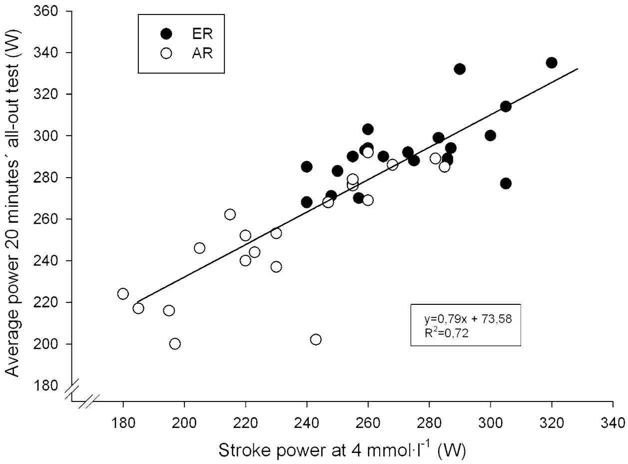

Fig. 3 The relationship between mean power output which elicited a blood lactate concentration of 4 mmol l^{-1} (W) and average power during 20-min all-out test (W)

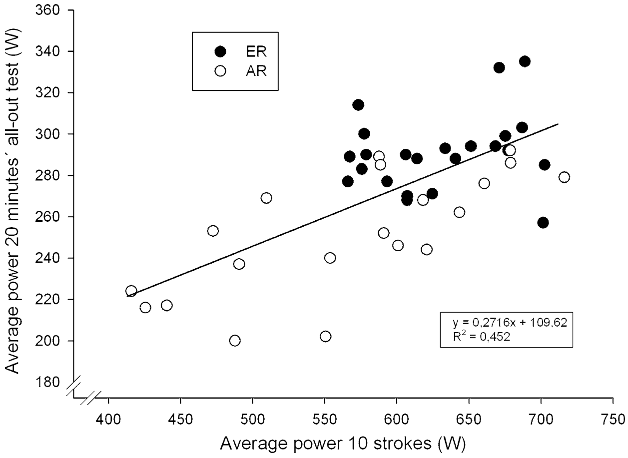

Fig. 4 The relationship between average power during 20-min all-out test (W) and mean power of ten strokes ($W_{10\ \mathrm{strokes}}$) (W)

Discussion

This is the first study carried out for identifying physiological factors of performance in high-level traditional rowers. The primary finding of this investigation indicates that elite level rowers (ER) in traditional rowing are characterised by higher body mass (5%), fat free body mass (5%), as well as higher values for maximal strength (13%), average index of bench-pull power-load (6–13%), and maximum number of repetitions until failure (19.3%), compared with the amateur level of rowers (AR). However, there were no differences between the two groups in terms of percentage of body fat and body height. In this study, higher values of mean stroke power output which elicited a blood lactate concentration of 4 mmol l^{-1} (17.8%), average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$) (15.4%), and mean power of ten strokes ($W_{10\ \mathrm{strokes}}$) (9%) were also observed in ER compared with the AR group. In addition, significant relationships were observed in the two groups between body mass and fat free body mass, and various indices of rowing performance ($W_{4\ \mathrm{mmol}\ l^{-1}}$ and $W_{20\ \mathrm{min}}$). In the AR group, the individual values of $W_{4\ \mathrm{mmol}\ l^{-1}}$ and $W_{20\ \mathrm{min}}$ correlated positively with different strength and muscle power values, whereas no significant relationships were observed in ER. Finally, significant relationships were observed between $W_{4\ \mathrm{mmol}\ l^{-1}}$ and $W_{20\ \mathrm{min}}$ in both groups.

To our knowledge, no studies have measured anthropometric, physical fitness (i.e. maximal strength, muscle power output) and rowing performance variables (i.e. $W_{4\ \mathrm{mmol}\ l^{-1}}$, $W_{20\ \mathrm{min}}$ and $W_{10\ \mathrm{strokes}}$)—characteristics of elite traditional rowers team (ER)—compared with an amateur team (AR). In any case, the ER team in the present study showed higher average body mass and fat free body mass but similar body height and percentage of body fat to those reported in the AR team. This shows that rowers with more muscle mass and who are more powerfully built are at an advantage in traditional rowing. In addition, it seems that the current average body height (182 cm) and body mass (84 kg) of these elite traditional rowers were lower (4.8 and 10%, respectively) than reported in other studies with international level Olympic rowers (i.e. Olympic champions) (191.3–193 cm and 90–96 kg, respectively) (Bourgois et al. 1998; Ingham et al. 2007). It is important to highlight the fact that higher body height and large body mass are favourable conditions in high level Olympic rowing performance (Ingham et al. 2002; Russell et al. 1998), influencing positively the long length of the rowing stroke (Secher 1993) and also the long stroke length (Ingham et al. 2002). The differences in body height and body mass could be related to a number of factors including: (a) biomechanical rowing style differences in traditional rowing technique (i.e. with fixed seat rowing) compared with that performed during Olympic rowing style and characterised by significant bending forward of the trunk at the beginning of the stroke followed by strong leg extension (Baudouin and Hawkins 2002). Differences in anthropometric characteristics could also be attributable to the fact that to complete a traditional rowing boat rowers with different anthropometric sizes are needed. One of the most important reasons is because for hydrodynamic reasons (Baudouin and Hawkins 2002), the 13 members of the boat must be well balanced enough to navigate in heavy seas. Because during traditional rowing, the length of the boat cannot be changed according to Rowing Federation regulations, the mechanical and physiological advantage gained in Olympic rowing with taller and more corpulent rowers may negatively influence traditional rowing technique and boat hydrodynamics. In addition, a more likely explanation could be attributable to the fact that traditional rowing, due to lower financial incentives and international competitions, has more difficulty in recruiting physically gifted, talented rowers than Olympic rowing.

One of the major findings in the present study was that maximal strength of the upper extremity muscles during bench-pull action was 13% higher in ER than in AR. Furthermore, the average power output index was 6–13% higher in ER than in AR. These strength and power differences between elite and lower level rowers may indicate that high absolute values of maximal strength and muscle power are required for successful performance in traditional rowing. However, when muscle power output was expressed in relative kilograms of fat free body mass, the differences between the elite and the amateur group disappeared. Similar to previous studies comparing strength and power differences between elite and lower level players (Gorostiaga et al. 2005; Izquierdo et al. 2002), these results may suggest that the patterns of neural activation and muscular tension by unit of muscular mass in the case of submaximal loads on the bench-pull exercise are similar between the high level group (ER) and the lower level (AR). On the other hand, the differences in body mass and lean mass could explain the differences observed between the groups in force and muscular power. Therefore, the higher levels of maximal strength and muscular power observed in the group of elite rowers provide a clear advantage to sustain a more powerful stroke during the oar cycle.

It was also interesting to observe that in rowing performance, the ER group gave higher power output values in $W_{20\ \mathrm{min}}$ (15.4%) and $W_{4\ \mathrm{mmol\ l^{-1}}}$ (17.8%) than reported in AR. These results agree with other studies (Bourdin et al. 2004; Ingham et al. 2002) which reported statistically significant differences between Olympic rowers in comparison with their corresponding amateur rower group. These results were very difficult to compare with others shown in scientific literature because our rowing performance test was run with a static seat. However, it must be pointed out that the previous average power output values in $W_{4\ \mathrm{mmol\ l^{-1}}}$ reported for an Olympic champion group (Ingham et al. 2007) were 43.7% greater than those reported in the present study (17.8%) in comparison with a corresponding amateur group. However, when the stroke power output that elicited a blood lactate concentration of 4 mmol $\mathrm{l^{-1}}$ and average power during the 20-min all-out test were expressed in relation to kilograms of body mass or fat free body mass, the differences between the elite and the amateur team in $W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$ disappeared or were less marked, as in the case of $W_{10\ \mathrm{strokes}}$. As in previous studies, it was also interesting to observe significant positive relationships in both groups between body mass and fat free body mass and various indices of rowing performance ($W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$) (Cosgrove et al. 1999; Secher 1993). This suggests that differences between elite and amateur rowers in average power output during ten maximal strokes ($W_{10\ \mathrm{strokes}}$), average power during the 20-min all-out test, and higher absolute values of stroke power output expressed in watts, which elicited a blood lactate concentration level of 4 mmol $\mathrm{l^{-1}}$, are mainly due to differences in muscle mass.

One of the purposes of this study was also to examine the relationships between anthropometric characteristics (i.e. fat free body mass), maximal strength and muscle power output (i.e. 1RM bench pull and power-load curve) and rowing performance in ER and AR groups. In the present study, stroke power which elicited a blood lactate concentration of 4 mmol $\mathrm{l^{-1}}$, mean power of ten strokes ($W_{10\ \mathrm{strokes}}$) and total power attained during a maximum number of repetitions leading to failure accounted for 81% of the performance variance in average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$). In addition, one repetition maximal bench-pull strength and total power attained during a maximum number of repetitions leading to failure with 75% of 1RM accounted for 38% of the performance variance in stroke power which elicited a blood lactate concentration of 4 mmol $\mathrm{l^{-1}}$. It indicates that those rowers with higher values of maximal strength and power index during bench-pull may be able to obtain higher values of performance in progressive endurance test versus those with lower values, regardless of the rower's standard. This finding suggest that maximal bench-pull strength plays an important role in the maximal work rate attained during a progressive rowing test in rowers, and that an increase in maximal strength of the upper body muscles, produced by heavy resistance strength training, led to an improvement in maximal rowing workload in rowers. As in the present study, Ingham et al. (2002) found that aerobic power and maximal power during the five strokes test were the strongest independent predictors of Olympic rowing performance over 2,000 m on the ergometer. In a group of highly trained Olympic rowers, Bourdin et al. (2004) reported peak power output sustained during maximal incremental testing as an overall index of rowing ergometer performance over 2,000 m in both heterogeneous and homogeneous group. These results suggest that high values of strength and power may be a determinant parameter in traditional rowing performance. In contrast with the previous observation, most international teams undertake very large amounts of low-intensity training in preparation for competition (Steinacker 1993). From the present results, it could therefore be suggested that force (i.e. maximal strength), power (i.e. $W_{10\ \mathrm{strokes}}$), as well as endurance capacity (i.e. $W_{20\ \mathrm{min}}$) may be important limiting factors for optimal traditional rowing performance. Finally, it was also interesting to observe significant relationship between $W_{4\ \mathrm{mmol\ l^{-1}}}$ and $W_{20\ \mathrm{min}}$ in both groups ($r =$ 0.65–0.80). This concurs with the results of previous studies (Ingham et al. 2002; Steinacker 1993) which reported that $W_{4\ \mathrm{mmol\ l^{-1}}}$ was the strongest determinant of performance on the rowing ergometer.

In summary, the results of this study show that elite traditional rowers are characterised by having greater body mass, a higher percentage of fat free body mass, and obtain significantly better results in the rowing performance test measured (i.e. average power during the 20-min all-out test ($W_{20\ \mathrm{min}}$), power output in 10 maximal strokes ($W_{10\ \mathrm{strokes}}$) and the stroke power associated with a blood lactate concentration of 4 mmol $\mathrm{l^{-1}}$ ($W_{4\ \mathrm{mmol\ l^{-1}}}$). In addition, elite traditional rowers had higher absolute values of maximal strength, muscle power-load curve and maximal number of repetitions until failure with 75% of 1RM during bench-pulls than amateur traditional rowers. Nevertheless, when these results were expressed with reference to the percentage of kilograms of their muscle mass, these differences disappeared. Furthermore, the indices of rowing performance suggested that $W_{20\ \mathrm{min}}$, $W_{4\ \mathrm{mmol\ l^{-1}}}$, $W_{10\ \mathrm{strokes}}$ and $Rep75_{\mathrm{sumBP}}$, followed by $1\mathrm{RM}_{\mathrm{BP}}$, are the most important predictors of traditional rowing performance in elite and amateur rowers.

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