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Longitudinal Study of an Olympic Lightweight Double-scul

Dissertação apresentada com vista à obtenção do grau de Mestre em Treino de Alto Rendimento Desportivo (Decreto-Lei nº. 74/2006 de 24 de Março), sob orientação do Professor Doutor José Augusto Santos e co-orientação do Professor Doutor Eduardo Oliveira.

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Palavras chave: REMO; PERFORMANCE; VO_{2max} ; LIMIAR ANAERÓBIO; COMPOSIÇÃO CORPORAL.

Keywords: ROWING; PERFORMANCE; VO_{2MAX} ; ANAEROBIC THRESHOLD; BODY COMPOSITION.

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Resumo

Objetivos: Descrever as variações fisiológicas e antropométricas de uma equipa Portuguesa de Remo, de classe mundial, durante um período de oito anos. **Métodos:** De 2005 a 2012 foram avaliados anualmente indicadores fisiológicos, antropométricos e de performance. **Resultados:** Durante o estudo, a massa corporal variou ligeiramente para os dois sujeitos S1 ($73.4\pm 0.6\text{kg}$) e S2 ($71.2\pm 0.5\text{kg}$), a massa gorda diminuiu aproximadamente 2% e a massa magra aumentou 1,3% e 3,1% para S1 e S2, respectivamente. O $\text{VO}_{2\text{max}}$ ($\text{L}\cdot\text{min}^{-1}$) aumentou 5,23% (S1) e 5,95% (S2) de 2005 a 2008. Entre 2009 e 2012 o $\text{VO}_{2\text{max}}$ ($\text{L}\cdot\text{min}^{-1}$) aumentou 23,1% (S1) e 11,79% (S2). O $\text{VO}_{2\text{max}}$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) registou um aumento entre 2005 e 2008 de 6,67% e 5,48% para o S1 e S2, respectivamente, e de 11,69% e 9,33% para S1 e S2, respectivamente, entre 2009 e 2012. A potência máxima aeróbia registou um aumento de 8,14% (S1) e 10,31% (S2) de 2005 para 2012. A potência ao limiar anaeróbio também aumentou. Para S1, de 2005 para 2008 o ganho foi de 5,62% e de 4,55% entre 2009 e 2012. Para o S2, de 2005 para 2008, o ganho foi de 8,33% e 5,4 entre 2009 e 2012. O lactato máximo aumentou igualmente quer de 2005 para 2008 e tanto para S1 (12.39%) como para S2 (21.78%); quer, de forma menos expressiva, entre 2009 e 2012 (S1=5.17%; S2=3.31%). A frequência cardíaca máxima registou um decréscimo durante os 8 anos na ordem dos - 2,62% e - 4,57% para S1 e S2, respectivamente. A performance no remo ergómetro (2005 – 2012) registou um aumento de 6.3% e 8.1% para S1 e S2, respectivamente. **Conclusão:** Este estudo demonstra que a melhoria da performance foi acompanhada pela melhoria do $\text{VO}_{2\text{max}}$ e do Limiar anaeróbio e foi seguida de uma redução na percentagem da massa gorda e um aumento da massa magra. Adicionalmente, observou-se que a performance no Remo pode ser melhorada até idades mais avançadas, aos 29-30 anos.

Palavras chave: REMO; PERFORMANCE; $\text{VO}_{2\text{max}}$; LIMIAR ANAERÓBIO; COMPOSIÇÃO CORPORAL

Abstract

Purpose: To describe anthropometrical and physiological variations of a Portuguese world-class lightweight rowing team throughout an eight-year-long period. **Methods:** From 2005-2012, anthropometrical, physiological and performance indicators were assessed annually. **Results:** During the study body mass varied slightly for both subjects, S1 (73.4 ± 0.6 kg) and S2 (71.2 ± 0.5 kg), body fat mass decreased approximately 2% and fat free mass increase 1.3% and 3.1% for S1 and S2, respectively. VO_{2max} ($L \cdot min^{-1}$) increased 5.23% (S1) and 5.95% (S2) from 2005-2008. From 2009-2012 VO_{2max} increased 23.1% (S1) and 11.79% (S2). Subject's VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$) improved from 2005-2008: 6.67% and 5.48% for S1 and S2, respectively; from 2009-2012: 11.69% and 9.33% for S1 and S2, respectively. Maximal aerobic power improved 8.14% (S1) and 10.31% (S2) from 2005 to 2012. Power at anaerobic threshold increased. For S1 from 2005 to 2008 the gain was 5.62% and 4.55% from 2009 to 2012. S2, from 2005 to 2008 the gain was 8.33% and 5.4% from 2009 to 2012. Maximal blood lactate increased: S1 (12.39%) and S2 (21.78%) from 2005 to 2008; S1 (5.17%) and S2 (3.31%) from 2009 to 2012. Maximum heart rate decreased over the 8 years: -2.62% and -4.57 for S1 and S2 respectively. Ergometer performance (2005-2012) improved 6.3% and 8.1% for S1 and S2, respectively. **Conclusion:** This study indicates that rowing performance can be improved until later in life. Performance improvement was parallel to the improvement of VO_{2max} and anaerobic threshold and were followed by a reduction in body fat mass and an increase in fat free mass.

Keywords: ROWING; PERFORMANCE; VO_{2MAX} ; ANAEROBIC THRESHOLD; BODY COMPOSITION

Abbreviations List

AT	Anaerobic Threshold
BF	Body Fat
BM	Body Mass
Erg _{Perf}	Ergometer Performance
FFM	Fat Free Mass
HR _{max}	Maximum Heart Rate
La _{max}	Maximum Lactate
P _{AT}	Power at Anaerobic Threshold
P _{VO₂max}	Power at Maximum Oxygen Uptake
VO ₂ max	Maximum Oxygen Uptake
W	Watt

INTRODUCTION¹

Rowing is generally described as a strength-endurance sport, lasting from 5.5 - 7.0 min, depending on boat class, gender and weather conditions (Maestu et al., 2005). During competition, aerobic and anaerobic capacities are stressed to their maximum (Steinacker, 1993). The energy demand during a rowing race is estimated to be 70-80% aerobic and 20-30% anaerobic (Maestu et al., 2005). Rowing technique and psychological factors may influence rowers' competitive level but ultimately rowing performance is directly related to rowers' physical and physiological characteristics (Maestu et al., 2005) as fat-free mass (Cosgrove et al., 1999), percentage of body fat and muscle mass (Morris & Payne, 1996; Slater et al., 2005) or VO_{2max} (Cosgrove et al., 1999; Nybo et al., 2014). These are variables that have a significant relationship with performance in lightweight category (Maestu et al., 2000).

However, because of their weight restrictions, lightweight rowers have more difficulty than heavyweight rowers in maintaining strength gains while improving their aerobic endurance, because strength improvement is related to muscle hypertrophy and therefore may result in body mass constraints. Though, lightweight rowers should increase their fat free mass, reducing their body fat to allow them to maximize their muscle mass while maintaining their weight category. The critical balance between strength and weight raises special challenges to these rowers in order to achieve and maintain the highest standards in their performance during an elite career. Because the difficulties to access to world-class athletes, physiological studies over a multi-year period in rowing are rare, especially for world-class rowers participating on Olympic or world championships. Only few longitudinal studies were conducted.

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Hagerman et al. (1996) studied the physiological alterations induced by a 20-year rowing career of the 1972 Olympic medallists; a ten-year study of a world-class sweep rower was conducted by Lacour et al. (2009), a six-year case study of a world champion quad crew was done by Mikulic (2011) and more recently a case study with a Danish lightweight rower investigating the relationship between competitive performance and physiological capacity (Nybo et al., 2014). Only one of these studies was realized in lightweight category. Nevertheless, the effect of time on rowing physiological and performance parameters remain rather unknown and may be puzzling as rowers may achieve outstanding results even after their late thirties while their physiological profile may decline in some variables. There are cases of Olympic successes in athletes very late into their careers (Sir Steve Redgrave, Eskild Ebbesen)

Some physiological variables can return to the highest level even after long periods of recovery (Nybo et al., 2014). After 20-25 years of age an age-related decrease in performance or in Maximal Oxygen consumption (VO_{2max}) has been reported (Donato et al., 2003; Evans et al., 1995; Hawkins & Wiswell, 2003; Jones, 1998; Messonnier et al., 1998; Tanaka & Seals, 1997). Mikulic (2011) in his six-year case study of a world champion quad crew from their 15-16 years of age, found improvements on body-mass, fat-free mass and VO_{2max} until the age of 20. After no further improvement was verified and mean values for all studied variables stabilized, suggesting that further substantial increases in VO_{2max} are difficult to achieve (Mikulic, 2011, p. 2365). Using a cross-sectional design with 29 elite oarsmen, Messonnier et al. (1998) also suggest that, VO_{2max} increases until 23 years of age and very slightly afterwards, independently of body-mass. In their review of O_2 consumption decline with aging, Hawkins & Wiswell (2003) also report a drop of 4% to 10% in master athletes after twenty years of age. Nevertheless, they suggest that the conjugation of aging with training reduction may partially be the cause of VO_{2max} loss in athletic individuals, concluding that an age-related loss of VO_{2max} seems to occur in a non-linear fashion in association with declines in physical activity/exercise (Hawkins & Wiswell, 2003). Jones (2006), in his eleven-year long case study, followed-up a marathon elite female athlete, reporting that VO_{2max} has remained relatively stable from 18 to 29

years although a dramatic improvement in performance was observed. Improvement in exercise economy over the years was suggested to explain those gains. The same author, in a five year case study of an Olympic runner reported a decline in VO_{2max} but an improvement in performance (Jones, 1998). However, Lacour et al. (2009), in an Olympic golden medallist, verified increases in VO_{2max} when he was 32 years. Though, even if a high VO_{2max} is a prerequisite for successful performance, other physiological factors may account for athletes' performance and its improvement, such as anaerobic threshold and strength. As reported by Mikulic (2011) also the power corresponding to VO_{2max} is an important parameter in monitoring rowing performance, as it has been frequently reported as strongly correlates with performance and predictor of 2000 m rowing ergometer performance (Maestu et al., 2005).

Another factor that decreases with aging is maximum heart rate (HRmax). The maximal HR decrease is the primary cause for the reduction of VO_{2max} with age (Heath et al., 1981). Despite this age-related decrease in maximal HR, it may be possible that this reduction is not always associated with a reduction of VO_{2max} (Nybo et al., 2014).

Due to the paucity of data on elite level rowers, this study represents a great opportunity to investigate the determinants of their high-class performance and the relationship with physical and physiological characteristics. Determined by the literature, that considers variables like VO_{2max} , AT, FFM as determinants of performance. This study aimed to describe anthropometrical and physiological variations of a Portuguese world-class lightweight rowing team throughout an eight yearlong period analysing: a) the long-term changes caused by rowing training in some physiological indicators; b) the correlation among some of the selected indicators and; c) how the alterations verified were related to performance evolution.

METHODS

Participants and data collection procedures

The present case study describes physical, physiological and performance development of two lightweight rowers, aged 21 and 22 when the study started, throughout an eight-year period, until the rowers were 29 and 30 years old. Their height was similar and remained stable during the study: 174 cm. When the study started their body mass was: Subject 1 (S1): 73.9 kg, Subject 2 (S2): 70.7 kg; competition weight was 70 kg for each subject. During the time of this longitudinal study, this world-class rowing crew raced exclusively in lightweight double-scul in international regattas, encompassing two Olympic cycles. During this period, the crew keep improving their results, moving from a D final in 2005 at the world championships to a B final in 2011. Their best results were 2nd place at the U23 world rowing championships, 2005, 3rd and 2nd place at the European rowing championships in 2011 and 2012, 8th place and 5th place in Beijing and London Olympic games, respectively (Table 1). Due to the constant increase of competition, it is difficult to objectify performance from final D to final A, as it's usual to see final A level rowers in the small finals at world championships.

Table 1. Performance highlights from 2005 to 2012

Year	Event
2005	2 th World Championship under-23. Amsterdam. Holland
2006	22 th World Championship. Eton. Great Britain
2007	14 th World Championships. Munich. Germany
2008	8 th Olympic Games. Beijing. China
2009	10 th World Championship. Poznan Poland; 5 th European Championship. Brest Belarus
2010	6 th World Championship. Kapiro. New Zealand 2 th European Championship. Montemor-o-Velho
2011	11 th World Championship. Bled. Slovenia 3 th European Championship
2012	5 th Olympic Games. London. Great Britain 2 nd European Championship

Between 2004 and 20012 athletes performed an average of 12 training sessions per week. Between 2004 and 2008 the team performed 114.5km / week with 66.6% of the training was specific rowing, 11.1% endurance land based training, 16.6% strength training and 5.5% core and flexibility.

Between 2008 and 2012 the team increased to 125km/week with 74% of the training specific rowing, 10% endurance land based exercise, 8% strength training and 8% core and flexibility. Training used is specified bellow (Table 2).

Table 2. Form and intensity definitions used to quantify training among olympic portuguese lightweight rowers

Term	Definition
Long distance rowing endurance training	Rowing at an intensity 60-75% VO_{2max} corresponding to blood lactate between 1 and 2.5 mMol/L.
Endurance land based training	Running or cycling at intensities corresponding to long-distance training in the boat.
Interval Training	Rowing at an intensity 80-90% VO_{2max} corresponding to blood lactate between 3.5 and 4.0 mMol/L with set distances between 1000 and 4000 meters.
Pace race	Intermittent sets distances between 250 and 1500 meters performed at velocity of 2000-meters race intensity- 100%.
Over speed training	Velocities above pace race >100% - 120%.
Strength training	Endurance, power and maximal strength training in land
Core-training	Exercises to prevent injuries and muscle / joint stability.
Flexibility training	Exercises to improve and maintain optimal range motion.

The anthropometrical, physiological and performance assessment included body mass, body composition, maximal oxygen uptake, anaerobic threshold (AT) and 2000m rowing ergometer power performances. All analysis were performed on an annual basis, on the preparatory period (January and February), at the Faculty of Sport's Physiology Laboratory (University of Porto), using the same procedures and equipment. Testing was always conducted by the same experimented laboratory's technician.

The procedure before the testing session was: a) a light train in the 24 hours preceding the test (12km at 50%-60% of their 2k max test), b) be fully hydrated and c) have a light breakfast in accordance to their usual habits, 90 minutes before arriving to laboratory and there was no particular nutritional advice. At all occasions both athletes gave their oral and written consent following the explanations of the procedures and the risks associated with the participation in accordance to the Helsinki Declaration. The Ethics Committee of the Scientific Counsel of Faculty of Sport of the Oporto University approved this study.

Measures

Maximal Oxygen Uptake Test ($\dot{V}O_{2max}$ L·min⁻¹). Expired respiratory gas fractions were measured using an open circuit breath-by-breath automated gas-analysis system (Cortex, Metalyzer, 3B, Leipzig, Germany). Before each test, flow, volume and gases were calibrated. Before the VO_{2max} test, the rowers were equipped with the proper instrumentation, the rowers warm-up during 5 minutes at 200 Watts (W) and start an incremental test of 25W every 2 minutes, starting from 250 W, on a stationary rowing ergometer with a drag factor of 130 (Concept 2, model D, Merrillville, VT, USA). The VO_{2max} (L·min⁻¹) was considered when at least two of the following conditions were verified: a plateau in oxygen uptake against exercise intensity, a value of respiratory exchange ratio ≥ 1.10 , a blood lactate ≥ 8 mmol·L⁻¹ and 90% of theoretical maximal HR, were achieved.

Heart Rate (HR) was measured and recorded every 5 seconds using a HR monitor (Vantage NV, Polar Electro, Kempele, Finland) that was connected with the gas-analyser system.

Metabolic Anaerobic Threshold. Metabolic anaerobic threshold was obtained during a step test on a rowing ergometer with 25 W increment every 5 minutes, with 1 minute rest for blood sampling. The test ended when 4 mmol·L⁻¹ was reached, using Lactate Pro Portable Lactate Analyser (Arkray, Japan). The warm-up was 5 minutes at 200 W and then the test start at 250 W.

Maximal 2000m-ergometer test. The all-out 2000 m performance test data were obtained during the national championships organized by the Portuguese Rowing Federation, between December and February, on a stationary rowing ergometer (Concept 2, Model D).

Anthropometrical assessments included the measurement of stature, mass and skinfold thickness. Body fat was estimated according to the skinfold thickness method developed by Jackson & Pollock (1978). Skinfold measurement was taken from seven sites (sub scapula, tricipital, midaxillary, supra-iliac, pectoral, abdominal, and thigh). Fat free mass was calculated by subtracting the estimated body fat from total body mass (BM).

Data Analysis

Descriptive data are expressed as absolute and relative values for both subjects. The alterations verified were expressed as percentage of variation. The relationship between specific variables was assessed by correlation coefficient (Spearman's). The significance level was set at $P < .05$.

RESULTS

During the study's period, this crew only raced as lightweight double-scul in major events. To facilitate data description and analysis we intent to highlight the main changes in the most critical measures according the two major cycles ending on the Olympic games. We also tried to highlight longitudinal tendencies on physiological and performance measures during the study. Absolute values are displayed on tables 3 and 4 for S1 and S2 respectively, along with percentage of variation over the eight-years studied period and through the Olympic cycles.

Table 3. Anthropometrical, physiological and performance changes from 2005 to 2012 and % of change for S1

	2005	2006	2007	2008	2009	2010	2011	2012	2005-2008	2009-2012	Total%
Body Mass (kg)	73.9	74.0	73.8	72.9	72.5	73.9	73.3	73.1	-1.35%	0.83%	-1.08%
Body Fat (%)	6.32	6.40	5.54	5.12	5.38	5.41	4.63	4.03	18.99%	25.09%	36.23%
Fat Free Mass (kg)	69.23	69.26	69.71	69.17	68.60	69.90	69.91	70.15	-0.09%	2.27%	1.34%
ERG _{Perf} (W)	421.4	432.3	435.1	446.6	442.2	433.7	439.4	448	5.98%	1.31%	6.31%
VO _{2max} (L·min ⁻¹)	5.54	5.77	5.76	5.83	5.10	6.13	6.15	6.28	5.23%	23.12%	13.37%
VO _{2max} (mL·kg ⁻¹ ·min ⁻¹)	75	78	78	80	77	83	84	86	6.67%	11.69%	14.67%
P _{VO2max} (W)	430	445	450	453	450	450	460	465	5.35%	3.33%	8.14%
La _{max} (mmol·L ⁻¹)	-	11.3	10.8	12.7	11.6	11.4	11.8	12.2	12.39%	5.17%	7.96%
P _{AT} (W)	320	325	330	338	330	327	332	345	5.62%	4.55%	7.81%
VO _{2maxAT} (mL·kg ⁻¹ ·min ⁻¹)	57	60	59	64	59	61	64	67	12.28%	13.56%	17.54%
VO _{2AT} (%VO _{2max})	76.0	76.9	75.6	80.0	76.6	73.5	76.2	77.9	5.26%	1.68%	2.51%
HR _{max}	191	189	185	187	184	187	185	186	-2.09%	1.09%	-2.62%

Table 4. Anthropometrical, physiological and performance changes from 2005 to 2012 and % of change for S2

	2005	2006	2007	2008	2009	2010	2011	2012	2005-2008	2009-2012	Total%
Body Mass (kg)	70.7	71.5	71.5	71.1	70.6	72.1	70.8	71.3	0.57%	0.99%	0.85%
Body Fat (%)	6.58	6.72	5.93	5.38	5.34	5.79	4.91	4.52	18.24%	15.36%	31.31%
Fat Free Mass (kg)	66.05	66.70	67.26	67.27	66.83	67.93	67.32	68.08	1.86%	1.87%	3.07%
ERG _{Perf} (W)	383.5	393.1	414.7	412.1	408.2	401.8	410.8	414.7	7.46%	1.59%	8.14%
VO _{2max} (L·min ⁻¹)	5.16	5.29	5.43	5.47	5.29	5.48	5.53	5.91	5.95%	11.79%	14.58%
VO _{2max} (mL·kg ⁻¹ ·min ⁻¹)	73	74	76	77	75	76	78	82	5.48%	9.33%	12.33%
P _{VO2max} (W)	388	399	420	422	415	413	420	428	8.76%	3.13%	10.31%
La _{max} (mmol·L ⁻¹)	-	10.1	11.6	12.3	12.1	9.4	11.9	12.5	21.78%	3.31%	23.76%
P _{AT} (W)	300	308	320	325	315	313	323	332	8.33%	5.40%	10.67%
VO _{2maxAT} (mL·kg ⁻¹ ·min ⁻¹)	53	54	58	59	55	56	62	66	11.32%	20.00%	24.53%
VO _{2AT} (%VO _{2max})	72.6	73.0	76.3	76.6	73.3	73.7	79.5	80.5	5.54%	9.76%	10.86%
HR _{max}	197	196	192	194	192	189	186	188	1.52%	2.08%	-4.57%

Anthropometry

For a lightweight crew the weight is a critical measure. Over the period of study, both subjects manage to maintain their body mass stable and no particular change was found during the eight years of this study: S1 ($73.4\pm 0.6\text{kg}$) and S2 ($71.2\pm 0.5\text{kg}$). In contrast with body mass stability, both subjects decrease their fat mass approximately 2% resulting on a 1.3% and 3.1% fat free mass increase for S1 and S2, respectively.

Physiology

Physiological measurements obtained in the present study showed a continuous improvement in $\text{VO}_{2\text{max}}$, both in absolute values or when related to body mass. From 2005 to 2012 both athletes improved their $\text{VO}_{2\text{max}}$ ($\text{L}\cdot\text{min}^{-1}$), being the second Olympic cycle where the biggest change occur. From 2005 to 2008 the rowers improved their $\text{VO}_{2\text{max}}$ ($\text{L}\cdot\text{min}^{-1}$) 5.23% (S1) and 5.95% (S2). On the second Olympic cycle (2009-2012) further improvements were verified: 23.12% (S1) and 11.79% (S2). Total $\text{VO}_{2\text{max}}$ improvement was 13.37% for S1 and 14.58% for S2.

When considering relative $\text{VO}_{2\text{max}}$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) the results were similar to the absolute values, with a continuous improvement during the period of study. First Olympic cycle (2005-2008): 6.67% and 5.48% for S1 and S2, respectively; Second Olympic cycle (2009-2012): 11.69% and 9.33% for S1 and S2, respectively. Total change: 14.67% for S1 and 12.33% for S2.

Maximal aerobic power ($P_{\text{VO}_{2\text{max}}}$ - power developed at $\text{VO}_{2\text{max}}$) also showed significant improvement. Overall the subjects improved 8.14% (S1) and 10.31% (S2). When testing their power at anaerobic threshold (P_{AT}) both rowers exhibited a positive change in their performance over time. For S1 from 2005 to 2008 the gain was 5.62% and 4.55% from 2009 to 2012. For S2, the values were slightly higher: from 2005 to 2008 the gain was 8.33% and 5.40% from 2009 to 2012.

Maximal blood lactate values also increased: S1 (12.39%) and S2 (21.78%) for the first Olympic cycle; S1 (5.17%) and S2 (3.31%) for the second Olympic cycle.

Maximum HR showed a tendency for decreasing over the 8 years period: -2.62% and -4.57 for S1 and S2 respectively.

Rowing Ergometer Performance

Maximal ergometer performance improved from the first to the last year of this study: 6.3% and 8.1% for S1 and S2, respectively.

Relationship between anthropometric and physiological characteristics and rowing performance

Some variables showed to be highly correlated with performance (Table 5).

Body Mass, relatively stable during the time of this study, is significantly correlated with ergometer performance ($r = .667, p < 0.01$), VO_{2max} ($r = .590, p < 0.05$) and $P_{VO_{2MAX}}$ ($r = .685, p < 0.01$).

Body Fat, which showed a decrease tendency over time, is significantly correlated with almost all variables measured on this study and in particular with VO_{2max} ($r = -.741, p < 0.01$), Maximal Blood Lactate ($r = -.783, p < 0.01$) and percentage of VO_{2max} at Anaerobic Threshold ($r = -.795, p < 0.01$). Fat-Free Mass showed an increase over time and significantly correlates with ergometer performance ($r = .845, p < 0.01$), with both absolute ($r = .828, p < 0.01$), and relative VO_{2max} ($r = .811, p < 0.01$) and with $P_{VO_{2MAX}}$ ($r = 0.905, p < 0.01$).

Ergometer performance significantly correlates with absolute VO_{2max} ($r = .828, p < 0.01$), Power at maximal oxygen consumption ($r = .977, p < 0.01$) and P_{AT} ($r = .893, p < 0.01$). Moreover, $P_{VO_{2MAX}}$ is significantly correlated with VO_{2max} both in its absolute and relative value ($r = .725, r = .830, p < 0.01$).

Table 5. Correlation between physical, physiological and performance variables

	BF (%)	FFM (Kg)	ERG _{Perf} (W)	VO _{2max} (L·min ⁻¹)	VO _{2max} (mL·kg ⁻¹ ·min ⁻¹)	P _{VO2max} (W)	La _{max} (mmol·L ⁻¹)	P _{AT} (W)	VO _{2max} AT (mL·kg ⁻¹ ·min ⁻¹)	VO ₂ AT (%VO _{2max})
BM (Kg)	.116	.836**	.667**	.590*	.457	.685**	-.373	.434	.346	.038
BF (%)	-	.412	.504*	.541*	.741**	-.50*	.783**	.750**	-.795**	-.553*
FFM (Kg)	-	-	.845**	.828**	.811**	.905**	.051	.764**	.707**	.259
ERG _{Perf} (W)	-	-	-	.616*	.754**	.977**	.345	.893**	.728**	.288
VO _{2max} (L·min ⁻¹)	-	-	-	-	.874**	.725**	.286	.726**	.821**	.599*
VO _{2max} (ml.kg ⁻¹ .min ⁻¹)	-	-	-	-	-	.830**	.405	.898**	.954**	.568*
P _{VO2max} (W)	-	-	-	-	-	-	.364	.916**	.784**	.331
Lamax (mmol·L ⁻¹)	-	-	-	-	-	-	-	.571*	.600*	.678**
P _{AT} (W)	-	-	-	-	-	-	-	-	.911**	.541*
VO _{2max} AT (ml.kg ⁻¹ .min ⁻¹)	-	-	-	-	-	-	-	-	-	.723**

P* < 0.05. *P* < 0.01

BM (Kg) = Body Mass (kg); **BF (%)** = Body fat; **FFM (Kg)** = Fat Free Mass; **ERG_{Perf} (W)** = Ergometer Performance (W); **VO_{2max}** = Maximal Oxygen Consumption; **P_{VO2max} (W)** = Power at maximal oxygen consumption; **Lamax (mmol.L⁻¹)** = Maximal Lactate; **P_{AT} (W)** = Power at Anaerobic Threshold; **VO_{2max}AT (ml.kg⁻¹.min⁻¹)** = Maximal Oxygen Consumption at Anaerobic Threshold; **VO₂AT (%VO_{2max})** = Percentage of VO_{2max} at Anaerobic Threshold.

DISCUSSION

This study aimed to analyse the evolution of several indicators in a lightweight rowing squad (double-scull) during two Olympic cycles (8 years).

Analysing anthropometric changes it must be highlighted the stability of body mass measures which are in line with the preoccupation for body mass control and crucial to maintain the subjects in their competitive category – lightweight.

Body mass stability was achieved through fat-free mass increase and body fat decrease, allowing these lightweight rowers to maximize their muscle mass while maintaining their weight category. In our subjects, fat free mass increase was closely related with the performance in rowing ergometer from 2005 to 2012. These findings are in accordance with Cosgrove et al. (1999) that showed a high correlation between fat free mass and velocity in the 2000m time-trial, highlighting fat-free mass as one of the best predictors of performance.

Also Ingham et al. (2002) found that fat-free mass strongly correlates with performance. This may be attributed to the association between fat-free mass, blood volume and stroke volume of the heart. The conjugation of these factors is crucial for successful performance in rowing (Mikulić, 2008). In fact, Slater et al. (2005), studying 66 elite rowers, found that successful lightweight rowers differed from their less successful counterparts because they presented lower body fat and greater total muscle mass.

Along with fat-free mass, VO_{2max} , both in absolute and relative values, has been emphasized as one of the best predictors of rowing performance in collegiate rowers (Cosgrove et al., 1999). However, the same relationship between FFM and performance was sated by Mikulic (2011) with elite level rowers. In fact, physiological measurements obtained in present study showed a continuous VO_{2max} improvement. From 2005 to 2012 both subjects improved their absolute VO_{2max} ($L \cdot min^{-1}$). However, it was at the second Olympic cycle (2009-2012), when our athletes were near their thirties, where the most impressive VO_{2max} gains

were observed (23.12% and 11.79%). Concerning the age of our athletes and the evolution of this variable, our findings conflict with the literature, as VO_{2max} has been reported to peak at the age of 20 years and no consistent subsequent changes are to be expected. Even if some studies found increases over time until the age of 23, specifically in rowing (Messonnier et al., 1998; Mikulic, 2011), or even about the age of 25 in cross-country skiers, as far as we know, no gains in VO_{2max} were observed after this age (Rusko, 1987). The continuous improvement in VO_{2max} of our athletes until close to their 30 years of age may be attributed to the fact that these athletes only started to be engaged with elite training process around the age of 21. The delayed entrance in the process of high level rowing training opened the possibility to increase some physiological capacities later in life.

It is likely that a better season training planning, a better manipulation of the training variables (intensity, duration and frequency) conjugated with the adequate rest between workouts is the reason for higher performance in our subjects.

A recent study with a lightweight rower (21 years study) reported the stability on VO_{2max} values throughout his career. The stability of well-developed physiological capacities seems to be important for the maintenance of high-level results rather than the improvement in technical and tactical skills (Nybo et al., 2014). In our subjects rowing performance was closely related to the improvement of the selected physiological indicators. This statement is corroborated by other authors who found that VO_{2max} (absolute and relative) were an important predictor in rowing performance. Moreover, the power developed at VO_{2max} is highly correlated with rowing performance (Ingham et al., 2002; Maestu et al., 2005; Mikulic, 2011).

High-level rowers are characterized by high rowing training volume. High training volume improves aerobic metabolism, which directly improves endurance and anaerobic threshold. Anaerobic threshold is an important parameter in rowing performance. In highly trained rowers, AT corresponds approximately to 80% - 85% of the maximum performance obtained in a 6-min all out rowing test

(Steinacker, 1993). The subjects in this study are out of this reference values. Subject 1 was always out of this range (74.6% - 77%) while subject 2 was close to the lowest value and inside this range for one time in 2012 (77.1% - 80.06%). The same author stated that AT is approximately 60 W lower than the power attained at the 6-min all out test. Our results conflict with this reference value because the power output at AT for S1 and S2 was 101.4 W to 112.2 W and 82.7 W to 94.7 W, respectively, lower than the maximal performance in the 2.000-m all out test (similar to the 6-min all out test). Power output at AT increased continuously in our subjects, although their values are comparative lower than the German elite studied by Steinacker (1993). Although the subjects were out of these reference values of German elite rowers, it was clear that they manage to improve their competitive level, which implies that other factor may have accounted to their performance like rowing technique (not evaluated in this study).

Blood lactate concentration after maximal rowing test, eliciting VO_{2max} , showed a trend to increase during the period analysed. Although, Steinacker (1993) has stated that maximum blood lactate decreases over time mainly due to the improvement of oxidative metabolism, our results contradict this sentence. In fact, our subjects improved their oxidative metabolism as can be seen by AT changes; however, as their VO_{2max} also increase substantially over time it is likely that maximal glycolytic metabolism was not attenuated by aerobic adaptations. This can justify the higher lactate concentrations seen in this study.

It is not clear the process underlying the age-related reduction in maximal HR (HR_{max}). Age alone explained the alterations induced by aging, usually maximum HR decreases 0.6 to 0.8 bpm (beats per minute) per year (Tanaka et al., 2001). Our results showed a reduction of HR_{max} over time and are corroborated by other study (Nybo et al., 2014). Even though both subjects reduced their HR_{max} , this reduction was not associated with VO_{2max} reduction. This finding is corroborated by Nybo et al. (2014).

CONCLUSIONS

The uniqueness of this study (2 consecutive Olympic cycles of lightweight rowing) strengthens the idea that rowing performance can be improved over time until later in life. These rowers started later (21 years old) in high level rowing training what permitted to verify a continuous improvement in rowing performance and racing results. Rowing performance improvement was parallel to the improvement of some physiological indicators as VO_{2max} , anaerobic threshold and glycolytic metabolism. The overall improvements were accompanied by a marked reduction in body fat mass and an increase in fat free mass.

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