©Journal of Sports Science and Medicine (2008) 7, 425-430
http://www.jssm.org

Research article

Training-level induced changes in blood parameters response to on-water rowing races

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Abstract
The study investigated blood markers allowing discriminating physiological responses to on-water rowing races, notably regarding training volume of athletes and race duration. College (COL) and national (NAT) rowers performed a 1000- or 2000-m race. Capillary blood samples obtained before and post-race allowed an analysis of a wide range of serum parameters. COL rowers had a lower rowing experience and training volume than NAT. Races induced a higher lactate concentration increase in NAT compared to COL (10.45 ± 0.45 vs 13.05 ± 0.60; $p < 0.001$). Race distance (2000 vs. 1000 m) induced a higher increase in fatty acids (0.81 ± 0.31 vs +0.67 ± 0.41; $p < 0.05$) and triglycerides concentration in NAT (0.33 ± 0.07 vs 0.15 ± 0.09; $p < 0.01$), but remained comparable between NAT and COL for the 1000-m races. Amino acids concentrations increased in NAT (0.19 ± 0.03, $p < 0.01$), but urea concentration increased only for NAT rowers having performed the 2000-m race (0.72 ± 0.22, $p < 0.05$). Transferrin concentration decreased after the 2000-m race (-0.60 ± 0.25, $p < 0.05$), and concentration changes of haptoglobin differed between NAT_{2000} (tendency to be reduced) and COL (tendency to by enhanced) ($p < 0.05$). Our results confirmed that the training level in rowing is associated with higher glycolysis utilization during maximal 1000- and 2000-m exercise and no difference for similarly trained subjects at these two distances. Our study also demonstrated that a 2000-m race could initiate fatty and amino-acid metabolisms in highly trained subjects. Therefore, these changes in blood parameter responses to a characteristic rowing exercise highlighted the importance of monitoring the physiological effects of training in sporting conditions and according to individual characteristics.

Key words: Energy metabolism, training, intensive exercise, endurance performance.

Introduction

The typical rowing race takes place over a 2000-m distance that lasts about 6-7 min, suggesting a major contribution of aerobic metabolism in energy supply for rowing performance (Hagerman et al., 1978; Messonnier et al., 1997). However, due to environmental conditions, most of the previous studies investigated rowing metabolic effects using an ergometer or sub-maximal exercises rather than on-water races (Jurimäe and Jurimäe, 2001; Urhausen et al., 1987; 1993). Some studies demonstrated that on-water sub-maximal exercises induced marked enhancement of carbohydrates and lipid metabolism whereas the catabolic effect of rowing was still a matter of debate (Dernbach et al., 1993; Jurimäe and Jurimäe, 2001; Petibois et al., 2003). Substrates utilization may be revealed by their arterial-venous differences or by intramuscular metabolites measurement. However such measurements are not allowed in on-water rowing and obviously during competitive events. Therefore very few studies investigated the metabolic effect (Jurimäe et al., 2006) of an on-water 2000-m race and a global description of blood content changes after on-water rowing races is still lacking (Mäestu et al., 2005).

Glucose and lactate, as well as triglyceride (TG), glycerol, fatty acids (FA), amino-acids (AA), and urea are usually observed as markers of exercise metabolic effects (Hartmann and Mester, 2000). Transport and hepatic proteins such as albumin, haptoglobin, transferrin, α_1-acid glycoprotein, α_1-antitrypsin, α_2-macroglobulin, and apolipoproteins A_1 (Apo-A_1), B (Apo-B) and C_3 (Apo-C_3) have been shown to play significant roles during exercise and to be sensitive to training (Armstrong and Warren, 1993; Petibois et al., 2003; Smith and Roberts, 1994). Taking into account that metabolic response depends on training experience and performance level, these parameters required to be accounted in the analysis of the metabolic response to on-water rowing races.

Fourrier transform infrared (FT-IR) spectrometry is a molecular analytical technique based upon the interaction of light with organic matter, revealing the molecular structure of every compound of a biological sample. The main advantages of this vibrational spectroscopy technique are 1- its sensitivity, 2- its reproducibility, 3- to be global, 4- to require few sample manipulations, and 5- to require no chemicals. This technique is also well suited for on-field sampling since only blood microsamples (~50 µl, easily and rapidly sampled at the fingertip) are required for determining concentrations of a wide range of biochemical parameters interrelated in their stimulation, flux, and regulation in response to exercise (Petibois et al., 2003). Thus, this technique provides useful metabolic information for the athlete and the coach in terms of training follow-up or monitoring (Petibois et al., 2000; 2002).

The aim of this study was to find blood markers that could highlight differences between populations in response to on-water races, notably regarding the influence of duration, training volume and experience. However, low experienced and trained adults rarely performed on-water rowing races on the 2000-m distance because of lower physical and technical competence. For example, college and masters official competitive races were performed on the 1000-m distance which corresponded to

Received: 07 April 2008 / Accepted: 28 May 2008 / Published (online): 01 December 2008

Table 1. College (COL) and national (NAT) rowers characteristics, training level and ergometer performance (2000-m exercise). Data are means (±SD).

	Age (years)	Height (m)	Weight (kg)	Rowing experience (years)	Training volume ($h \cdot week^{-1}$)	Ergometer performance (sec)
COL	21.1 (.2) $#	1.81 (.01) $#	74.1 (1.8) $#	2.5 (.4) $#	4.8 (.4) $#	-
NAT_{1000}	25.3 (.9) *	1.85 (.01) *	80.5 (1.8)	12.1(.7) *	11.5 (.8) *	389 (2.9)
NAT_{2000}	24.6 (1.1) *	1.85 (.01) *	79.8 (1.4) *	11.4 (1.1) *	12.8 (.7) *	383 (3.6)

* denotes significantly ($p < 0.05$) different from COL. $ denotes significantly ($p < 0.05$) different from NAT_{1000}. # denotes significantly ($p < 0.05$)different from NAT_{2000}.

the "short" distance for national rowers. Then, the metabolic effect of maximal on-water rowing races was tested on college (1000-m) and national rowers (1000 and 2000-m). These two types of rowers and race distances allow the detection of the particular influence of training levels, rowing experience and race duration on the metabolic response that could be observed.

Methods

Subjects

A total of 59 athletes participated in this study after a full explanation of the risks and benefits of the study. Subjects gave their written informed consent for participating in accordance with the medical committee of the French Rowing Federation. The sample population comprised three groups of French rowers who competed in varied official events. The first group comprised college rowers (COL; n = 17), the second group comprised national rowers competing on 1000-m races (NAT_{1000}; n = 19), and the third group comprised national rowers competing on 2000-m races (NAT_{2000}; n = 23), 15 subjects both belong to the second and third groups.

Study design

Blood samples were collected at rest and immediately post-exercise: *i)* during a national championship for COL (race distance of 1000-m; Bordeaux, France); *ii)* during the International Regatta of Bordeaux (France) for NAT_{1000} (race distance of 1000-m; Bordeaux, France); and *iii)* during national championships for NAT_{2000}. 1000-m races were performed at the same place and were separated by two weeks; all the races were performed in good environmental conditions. Rowers competed maximally in the study races as the best placing induced lower level of the adversary in the next round.

All subjects were in post-absorptive condition, with their last meal at least 2.5 hours before blood collection. Capillary blood samples of ~50 µl were drawn before the warm-up that preceded the race (after a 5-min sited rest period) and immediately after the race (3-4 minutes after exercise completion) using a standard lancet device (Softclix Pro, Boehringer-Manheim, Germany) and gel-barrier collection tubes for microsamples (Microtainer, Becton-Dickinson, USA).

Training level and rowing performance

Training volume was determined after discussion with athletes and coaches, and from individual training diaries before the race. The number of years in rowing training was considered as the "rowing experience". To identify the level of physical performance of NAT, we recorded 2000-m rowing ergometer (Concept II type C, Morrisville, USA) performance realized during official competitive events in the 2-3 months preceeding the study. In our groups; all NAT rowers frequently performed such test whereas many COL did not, therefore ergometer performance in COL could not be recorded. The duration (in seconds) and length (in meters) of the race on which blood samples were collected were used for determining race velocity.

Blood analyses

After sampling, blood was immediately centrifuged (3 min at 15000*g*) and then stored at -20°C before analysis. Serum concentrations of glucose, lactate, TG, glycerol, FA, AA, urea, albumin, haptoglobin, transferrin, α_1-acid glycoprotein, α_1-antitrypsin, α_2-macroglobulin, Apo-A_1, Apo-B, and Apo-C_3 were determined by FT-IR spectrometry according to the methods previously described using an IFS 28/B spectrometer (Bruker, Germany) (Petibois et al., 2000; 2002). The change in plasma volume between rest and post-race was determined according to the method previously described (Petibois et al., 2003). All analyses were performed in triplicate.

Statistical analyses

Differences between rowers and races characteristics were tested with unpaired *t*-test. The repeated-measures analysis of variance (ANOVA) were used for two factors (blood sampling time × blood concentration; groups × blood concentration change) and the Tukey post-hoc test to identify significant differences in concentration changes according to sampling times and groups. We used Pearson product-moment correlation coefficients to determine the relationship between blood parameters, rowers training characteristics and race velocities. All statistics were performed using the Statistica 6.1 software package (Statsoft, France). The level of significance for all analyses was set at $p < 0.05$. Data are expressed as mean ± SEM.

Results

Training level and rowers characteristics

Table 1 presents mean age, height, weight and training characteristics of rowers. COL was significantly younger, smaller, and lighter than NAT_{1000} ($p < 0.05$). COL rowing experience and training volume were significantly lower than those of NAT's experience (both; $p < 0.001$). Ergometer performances were similar in NAT groups. NAT_{1000} race duration was lower than COL (181 ± 2.7 vs

Table 2. Plasma concentrations of metabolic parameters at rest and after the rowing race. Molecular concentrations corrected for plasma volume change and expressed in mmol·l^{-1} excepted for Amino-acids expressed in g·l^{-1}. Data are means (±SD).

	COL rest	concentration change	NAT_{1000} rest	concentration change	NAT_{2000} rest	concentration change
Glucose	4.7 (.13)	.37 (.13)	5.17 (.34)	.47 (.21)	5.02 (.13)	.25 (.10)
Lactate	1.12 (.07)	10.45 (.45)£$#	.95 (.07)	13.05 (.6)£*	1.00 (.07)	13.79 (.44)£*
Fatty acids	9.21 (.29)	-1.45 (.03)$#	8.86 (.52)	.67 (.41)*	9.09 (.22)	.81 (.31)£*
Triglycerides	1.32 (.07)	.13 (.08)	1.36 (.09)	.15 (.09)	1.40 (.07)	.33 (.07)£*
Glycerol	.05 (.0)	.06 (.01) £#	.04 (.00)	.06 (.01) £#	.05 (.00)	.15 (.01)£$*
Amino acids	.34 (.01)	.02 (.02)$#	.33 (.02)	.19 (.03) £*	.34 (.01)	.19 (.02)£*
Urea	6.25 (.36)	.17 (.06)	5.51 (.41)	.04 (.31)	6.03 (.26)	.72 (.22) £

£ denotes significantly ($p < 0.05$) different from rest concentration. * denotes concentration change significantly ($p < 0.05$) different from COL. $ denotes concentration change significantly ($p < 0.05$) different from NAT_{1000}. # denotes concentration change significantly ($p < 0.05$) different from NAT_{2000}. COL = College rowers, NAT = national rowers.

218 ± 6.4 s, $p < 0.01$), obviously NAT_{2000} race duration (402 ± 4.5 s) was largely higher than those of COL and NAT_{1000} ($p < 0.001$). These durations provided significantly higher race velocities for NAT_{1000} compared to NAT_{2000} (respectively, 5.5 ± 0.07 vs 5.0 ± 0.05 m·s^{-1}; $p < 0.01$) and COL (respectively, 5.5 ± 0.07 vs 4.6 ± 0.1 m·s^{-1}; $p < 0.01$), and higher for NAT_{2000} compared to COL ($p < 0.05$).

Race effects on metabolic parameters

No race effect was observed in plasma glucose concentrations for any group (Table 2). Racing induced a significant increase of blood lactate concentrations in all groups ($p < 0.0001$), but this increase was significantly higher in NAT_{1000} and NAT_{2000} compared to COL ($p < 0.001$). Race-induced lactate concentration change was also found correlated to rowing experience, training volume and race velocities (Table 3; $p < 0.05$). Post-race FA concentrations remained stable in COL and NAT_{1000}, but increased in NAT_{2000} ($p < 0.05$). On the other hand, marked differences appeared in race-induced FA concentration changes between COL and NAT_{1000} (respectively, - 1.45 ± 0.03 vs + 0.67 ± 0.41 mmol·l^{-1}; $p <0.01$), as well as between COL and NAT_{2000} ($p <0.01$). These changes in FA concentrations were found correlated to rowing experience, training volume, and races duration ($p < 0.05$). An increase in TG was observed post-race in NAT_{2000} ($p < 0.01$) whereas no change was observed in COL ($p = 0.1$) and NAT_{1000} ($p = 0.08$). The race induced an increase in glycerol concentrations for all groups ($p <0.001$), but it was higher in NAT_{2000} than in COL and NAT_{1000} ($p < 0.001$ and $p < 0.01$, respectively). This concentration change was correlated to race duration ($p < 0.05$). AA concentrations remained stable between rest and post-race in COL, but an increase was observed in NAT_{1000} ($p < 0.01$) and NAT_{2000} ($p < 0.0001$). Therefore, significant differences could be found between COL and the two other groups ($p < 0.001$). A race-induced increase in urea concentration was also observed for the NAT_{2000} group ($p < 0.05$), whereas no change was found for COL and NAT_{1000} (respectively, $p = 0.06$ and $p = 0.09$). Concentration changes of urea were related to race duration ($p < 0.05$).

Races effects on proteins

No race effect was observed on albumin and total protein concentrations (Table 4). Transferrin concentration was found unchanged post-race in COL and NAT_{1000} whereas a decrease occurred in NAT_{2000} ($p < 0.05$). The transferrin concentration change was correlated to race durations ($p < 0.05$). Race-induced change in haptoglobin concentrations differed between COL and NAT_{2000} (respectively, + 0.24 ± 0.08 vs – 0.15 ± 0.09 g·l^{-1}; $p < 0.05$). No race effect was observed on concentrations of α_1-antitrypsin, α_2-macroglobulin, and α_1-acid glycoprotein. However, concentration change in α_1-acid glycoprotein differed between COL and NAT_{2000} (respectively, + 0.14 ± 0.07 vs – 0.05 ± 0.06 g·l^{-1}; $p < 0.05$). Apo-A_1 and Apo-B concentrations remained unchanged post-race, whereas an increase was observed for Apo-C_3 in NAT_{1000} and NAT_{2000} ($p < 0.01$ and $p < 0.001$, respectively). Apo-C_3 concentration change was found correlated to training volume, race duration and race velocities ($p < 0.05$).

Discussion

This study was the first to report specific responses of blood markers to on-water rowing races in two populations. Similar training status, rowing experience and physical performance were observed in NAT_{1000} and NAT_{2000}, whereas COL presented lower training level and experience than NAT.

Table 3. Matrix of significant Pearson product moment correlation of race-induced blood markers concentration change with rowing exerience, training volume, race duration and race velocity.

	Rowing experience	Training volume	Race duration	Race velocity
Lactate	.52	.48	n.s.	.55
Fatty acids	.51	.49	.39	n.s.
Glycerol	n.s.	n.s.	.65	n.s.
Urea	n.s.	n.s.	.78	n.s.
Transferrin	n.s.	n.s.	-.44	n.s.
Apo-C_3	n.s.	.52	.62	.69

n.s. non-significant.

Table 4. Plasma concentrations of transport and hepatic proteins at rest and after the rowing race. Molecular concentrations changes corrected for plasma volume change and expressed in g·l^{-1}. Data are means (±SD).

	COL rest	concentration change	NAT_{1000} rest	concentration change	NAT_{2000} rest	concentration change
Albumin	41.5 (.5)	-.86 (.61)	38.9 (2.1)	.45 (.71)	39.9 (.4)	.50 (.41)
Haptoglobin	2.07 (.07)	.24 (.09) #	2.16 (.13)	.18 (.11)	2.26 (.11)	-.15 (.11) *
Transferrin	2.84 (.11)	.30 (.11) #	2.81 (.15)	.24 (.11) #	3.54 (.23)	-.60 (.25) £*$
α_1-antitrypsin	2.86 (.08)	.15 (.03)	2.64 (.15)	.24 (.10)	3.01 (.17)	.04 (.10)
α_2-macroglobulin	1.92 (.08)	.45 (.03)	2.01 (.12)	.21 (.12)	2.04 (.09)	-.08 (.11)
α_1-acid glycoprotein	1.06 (.05)	.14 (.09) #	1.02 (.06)	.11 (.07)	1.12 (.07)	-.05 (.08) *
Apo-A_1	1.33 (.05)	.06 (.04)	1.25 (.07)	.05 (.06)	1.30 (.03)	.06 (.03)
Apo-B	1.01 (.04)	.07 (.05)	.99 (.06)	.07 (.06)	1.04 (1.03)	.07 (.02)
Apo-C_3	.09 (.01)	.02 (.09) #	.07 (.01)	.11 (.01) £*	.12 (.01)	.15 (.01) £*

£ denotes significantly ($p < 0.05$) different from rest concentration. * denotes concentration change significantly ($p < 0.05$) different from COL. $ denotes concentration change significantly ($p < 0.05$) different from NAT_{1000}. # denotes concentration change significantly ($p < 0.05$) different from NAT_{2000}. COL = College rowers, NAT = national rowers.

Responses of energetic substrates to 1000-m races

NAT_{1000} presented a higher lactate concentration increase compared to COL, and lactate concentration changes were found correlated to training volume and rowing experience. Thus, physical conditioning of NAT is likely to have enhanced the muscles capacity to deliver higher energy output from glycolysis and/or NAT could be able to maintain high boat speed despite fatigue and acidosis increase when COL were not (Lacour et al., 1990; Messonnier et al., 1997). In addition, since skill is also primarily due to rowing experience which was related to blood lactate increase, the inability for COL rowers to go as fast as NAT rowers may be due to their lower technical ability. Therefore, the lower blood lactate concentrations of COL could be due to lower speed as a result of their skill level rather than their capacity to tolerate lactate. Whatever the reasons of these differences, maximal blood lactate concentration after all-out exercise could differ according to athlete's fitness and training states supporting the assessment of individual maximal lactate for the monitoring of rowers over prolonged training periods (Jeukendrup and Hesselink, 1994; Lacour et al., 1990).

NAT_{1000} and COL had similar responses in lipid metabolism after exercise, i.e., no change in glycerol concentration, whose increase could have underlined a significant triglycerides hydrolysis. In this context, the difference observed in the race-induced changes of FA concentration between NAT and COL appears as a peculiar change that was probably not sufficient to demonstrate a significant utilization of lipid metabolism in NAT_{1000} but probably a sign of a mobilization of energetic substrates that was faster in NAT than in COL. This was probably originated from training as FA changes were found correlated to rowing experience and training volume as previously suggested (Jurimae et al, 2006). Conversely, the enhanced glycolysis observed in NAT rowers, which is demonstrated by the increased concentration of lactate without changes in blood glucose, could limit FA availability in the muscle reducing the possibilty of fat use during exercise (Sidossis and Wolfe, 1996).

Responses of energetic substrates to 1000 and 2000-m races in NAT rowers

Differences in race-induced changes in glycerol and FA concentrations appeared between NAT groups, the former increased in NAT_{2000} but the latter was not different between groups. Race-induced change in glycerol and in FA concentrations indicate lipolysis and enhanced FA availability, respectively, NAT_{2000} could have a greater utilization of lipid than NAT_{1000}. 2000-m races have a duration that requires a different metabolic regulation than 1000-m races, an observation that was reinforced by the relationship between the training volume and race-induced changes in Apo-C_3 concentration. Apo-C3 is the protein responsible for TG transport within blood, but not of its mobilization. In NAT rowers, high intensity exercise was associated with an acute increase in Apo-C_3 concentration, which could facilitate TG mobilization. However, concomitant increases in FA and TG concentrations occurred only in NAT_{2000}. The enhancement of lipid availability was only initiated in NAT_{1000}, but marked in NAT_{2000}, highlighting adaptation to endurance training that allows to better undertake the exercise duration of 2000-m races compared to 1000-m . Then, NAT_{2000} presented higher utilization of oxidative metabolism, as underlined by the changes in lipidic markers in blood after exercise. Conversely, NAT_{1000} and NAT_{2000} differed in race velocity, but not in rowing experience, training volume and physical performance that resulted in similar changes in blood lactate concentrations in the two groups whereas 1000-m race was expected to enhance the glycolytic pathway (Lacour et al., 1990). Because lactic-acid production has a limit for any athlete, this result suggested that NAT reached this limit in 1000 and 2000-m race. Despite the suggested predominance of the oxidative metabolism in 2000-m race, the final sprint in the race could have allowed NAT_{2000} to reach their maximal lactic-acid production (Garland, 2005). For elite rowers (such as NAT in our study), the major part of training volume is performed at intensities supposed to be moderate (i.e.; lower than 3 mmol.L^{-1} lactate) (Bourdin et al., 2004; Steinacker et al., 1998). One may consider that this type of training is primarily designed to improve oxidative metabolism and skill for 2000-m races. A specific training program for 1000-m distance with exercises performed at higher intensities, lower duration, lower rest pauses should modify the effects of such races on glycolysis (Lacour et al., 1990).

Race effects on transport and hepatic proteins concentrations

The rowing exercise effects on protein catabolism or muscle damage is still in debate. Protein metabolism is not measured by the release of AA during a race lasting only a few minutes, however or results demonstrated that race duration led to different responses in inflammatory proteins. AA concentrations were increased in NAT but not in COL, and urea concentrations increased only after the 2000-m race. Moreover, race-induced concentration changes of α_1-acid glycoprotein differed between COL and NAT_{2000}. An increase in α_1-acid glycoprotein concentrations could occur in response to tissue inflammation and muscle wasting in moderately trained subjects, while a decrease is usually observed after an exercise in highly trained rowers (Petibois et al., 2003). The AA, urea and α_1-acid glycoprotein responses to the 2000-m race could contribute to a greater stimulation of protein synthesis post-exercise depending on the high training volume of NAT (Biolo et al., 1995; Phillips et al., 1999). Despite the fact that these particular responses were linked to training level, the 2000-m race should also induce a marked energetic metabolic stress resulting in specific responses. That was suggested by the decrease of transferrin and haptoglobin concentrations observed in NAT_{2000}, and by the negative relationship found between race duration and transferrin concentrations in NAT_{2000}. Thus, the high intensity sustained during the 2000-m race (about 6 minutes of high intensity exercise) induced a significant stress of blood cell system and iron metabolism, possibly due to the high oxidative flux of such exercise (Schumacher et al., 2002). However, post-race protein concentrations were found within the normal physiological range suggesting that this slight oxidative stress could be easily reversed after exercise.

Conclusion

Our study demonstrated that the 2000-m compared to 1000-m races in NAT rowers could initiate fatty and amino-acid metabolisms. Increase of FA availability suggested that NAT rowers over 1000-m races could mobilize faster energetic substrates than COL. Therefore, compared to the 1000-m, the 2000-m race induced marked disruption of rowers physiological status highlighting specific adaptations to rowing maximal exercise. The ergometer has been supposed to overestimate the anaerobic contribution to total work output, and maximal test requires total investment of subjects that could be impractical frequently in the sport season and in opposition to the sport season goals. Therefore, these changes in blood parameters in response to a characteristic rowing exercise highlighted the interest to monitor the physiological effects of training in usual sport conditions and according to individual characteristics.

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Key points

- Rowing races despite their short duration could initiate fatty and amino-acids metabolisms.
- Effects of maximal exercise on metabolic blood parameters depend on individual capabilities, suggesting that the effects of exercise or training on a given blood parameter may be monitored relatively to individual maximal concentrations rather than by inter-individual comparison.
- High training level may lead to marked disruption of homeostasis which could be easily reversed by high recovery capabilities.

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