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Research article

The Effect of Upper Body Anaerobic Pre-Loading on 2000-m Ergometer-Rowing Performance in College Level Male Rowers

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Abstract
Elevated blood lactate has been shown to influence subsequent anaerobic exercise due to an inhibition of glycolysis. The aim of the present study was therefore to investigate the influence of a short and high-intensity anaerobic arm crank pre-load exercise (HIE) added to a low-intensity warm-up on cardio-respiratory and metabolic responses on a subsequent all out rowing exercise. Nine well-trained college level male rowers (24.6 ± 7.1 yrs; 1.87 ± 0.07 m; 88.9 ± 9.8 kg; 18.5 ± 3.7% body fat) volunteered to participate in the study. The subjects performed a maximal 2000-m rowing ergometer performance tests (MPT) twice. One MPT was preceded by a normal low intensity warm-up (MPT_{low}), while another one was performed with the additional inclusion of the HIE protocol (MPT_{high}). Overall rowing performance in the MPT_{low} was significantly faster ($p = 0.004$) by 3.7 ± 2.8 sec compared to the MPT_{high} condition (401.7 ± 23.0 s v. 405.4 ± 23.3 s) but the reduction in speed was found only for the first 1000-m ($p = 0.017$). Net La increase from rest to the end of the MPT_{low} was 11.9 ± 2.3 $mmol \cdot l^{-1}$ which was significantly higher ($p = 0.0001$) compared to the MPT_{high} condition (6.3 ± 1.8 $mmol \cdot l^{-1}$). Carbon dioxide output was significantly lower in the second ($p = 0.041$), third ($p = 0.009$), fourth ($p = 0.036$) and fifth ($p = 0.028$) 250-m split in the MPThigh compared to the MPTlow test. In conclusion, HIE upper-body anaerobic pre-load added to a standard low intensity warm-up protocol decreased anaerobic performance only in the early stages of the MPThigh but the latter part was unaffected. The inhibition of glycolysis in the first minute of the workout might allow a different race strategy, which needs to be investigated in further studies.

Key words: Rowing, net-lactate increase, warm-up exercise.

Introduction

Competitive rowing is considered to be one of the most physiologically demanding sports, as rowers work near their maximal physical capacities and about 70% of the whole body muscle mass is recruited during rowing (Mäestu et al., 2005). According to Roth et al. (1983) the 2000-m rowing race was performed with 67% aerobically, 33% anaerobically, 21% alactic and 12% lactic energy contribution.

One of the purposes of warm-up is to prepare the organism for high intensity work and to speed up aerobic energy production. Therefore, warm-up is an integral part of the preparation before the start of a 2000-m rowing race. Warming-up prior to a competitive exercise bout is a widely accepted practice in sports, with athletes and coaches alike believing that warming-up is essential for attaining optimal performance (McGowan et al., 2015). It is not possible to have similar warm-up protocol for all sports and athletes, therefore athletes search the best practice to prepare for their competition (Mujika et al., 2012). Alternatively, athletes use one specific warm-up protocol, which has successfully been applied previously by other athletes or during their own practice (McGowan et al., 2015).

An active warm-up is a routine performed by most athletes to improve competitive performance. Previous studies have demonstrated that a number of physiological changes occur with active warm-up, some of which are potentially capable of improving performance, particularly during high-intensity exercise (Bishop, 2003). This practice probably increases muscle temperature, nerve conduction rate, speed of metabolic reactions, oxygen uptake kinetics, muscle post activation potentiation, and psychological preparedness (Bishop, 2003). Other studies have found conflicting results, suggesting that active warm-up does not produce significant physiological changes that might be expected to enhance performance (Hajoglou et al., 2005). When recovery of 15±6 min was introduced between a high-intensity warm-up and competition exercises, there was an improvement in maximal peak power (Sargeant, 1987). Apparently, the rate of muscle glycogenolysis and blood lactate (La) production as well as performance are reduced when a high-intensity exercise bout is preceded by very intense exercise (Bangsbo et al., 1993; Gaitanos et al., 1993), however it is unclear what causes these changes and what the role of lower levels of muscle glycogen and pH are.

Muscle glycogen concentration does not appear to influence the rate of glycogenolysis (Bangsbo et al., 1993). It has also been demonstrated that glycogen breakdown and La accumulation were reduced when muscle glycogen was low (Iaia et al., 2010). La production can also be low during intense exercise although the muscle glycogen concentration is high as it may be suggested that elevated lactate levels influence the rate of glycolysis in a subsequent anaerobic workout (Bishop et al., 2001; Gray and Nimmo, 2001; Robergs et al., 1991). La increase by arm exercise decreased the rate of La accumulation in a subsequent cycle ergometer sprint by approximately 50% (Bogdanis et al., 1994). A similar effect has been shown by Iaia et al. (2010), Mavrommataki et al. (2006) and Müller et al. (2013) who investigated the effect of previous high-intensity anaerobic exercise on metabolism and fatigue development during intense exercise. Mavrom-

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mataki et al. (2006) found, that power output recovery during repeated maximal bouts of rowing exercise were incomplete after 6 min of rest. Müller at al. (2013) further reported that the pre-elevation of La markedly inhibited net La concentration, which might be beneficial due to a shift to an increased oxidative metabolism if not maximal anaerobic contribution such as in sprint exercise is needed. Burnley et al. (2006) demonstrated that the characteristic effect of priming exercise on VO_2 kinetics occurred only when there was a physiologically significant elevation in the baseline La. In contrast, a short high-intensity non-specific exercise bout before an all-out competition like exercise may therefore act as a priming effect, which speeds up VO_2 kinetics important for a major part of the race duration, which has been shown recently for cycling (Burnley et al., 2011). In that study it was shown that heavy-intensity priming exercise increased aerobic contribution early in exercise, reduced the amplitude and trajectory of the VO_2 slow component and increased VO_{2peak}, providing a greater scope for the VO_2 response (Burnley et al., 2011). Primed VO_2 kinetics may have served to reduce the rate of substrate-level phosphorylation and delayed the attainment of VO_{2peak}, which might have resulted in an increase in time to exhaustion and therefore power (Burnley et al., 2011).

The aim of the present investigation was to investigate how a short and high-intensity anaerobic non-rowing specific arm crank pre-load exercise added to a low-intensity warm-up affects 2000-m rowing ergometer performance. It was hypothesized that 2000-m maximal rowing ergometer work is not significantly influenced by an inhibition of glycolysis due to a pre-elevated lactate concentration by a non-specific anaerobic bout of exercise, which is compensated by an accelerated oxygen uptake.

Methods

Participants

Nine college level male rowers (age: 24.6 ± 7.1 yrs.; body height: 1.87 ± 0.07 m; body mass: 88.9 ± 9.8 kg; body fat: 18.5 ± 3.7%) volunteered to participate in the study. Measurements took place at the end of the preparatory period and before the first on-water competition. All rowers have been taking part to rowing training for at least the last 5 years and have competed several times in on-water rowing and rowing ergometer competitions. The rowers were fully familiarized with the procedures before providing their written consent to participate at the experiment as approved by the Medical Ethics Committee of the local university.

Body composition

The height (Martin Metal Anthropometer) and body mass (A&D Instruments, UK) of the participants were measured to the nearest 0.1 cm and 0.05 kg, respectively. Body composition was measured using dual-energy X-ray absorptiometry. Scans of the whole body were performed on each of the subjects using a Hologic Discovery DXA scanner (Hologic, Marlborough, USA) and analyzed for body fat (FM) and fat free (FFM) mass.

Incremental ergometer exercise

A progressive test to exhaustion was performed on a rowing ergometer (Concept II, Morrisville, VT, USA). The test started at an initial work rate of 40 W with increments of 20 W after every minute until fatigue. Throughout this test, VO_2 was measured breath-by-breath with the data analyzed as 5-s averages to determine the respiratory exchange parameters, maximal oxygen consumption (VO_{2max}; $l·min^{-1}$), relative VO_{2max} ($VO_{2max/kg}$; $ml·min^{-1}·kg^{-1}$), respiratory exchange ratio (RER), maximal ventilation (VE; $l·min^{-1}$), maximal aerobic power (P_{max}; W), and first (VT_1) and second (VT_2) ventilatory thresholds (Cortex MetaMax 3B, Germany). The analyzer was calibrated with Cortex calibration gases of known concentration before each test and a 3-L standard syringe was used to calibrate the turbine volume transducer (Hans Rudolph, Kansas City, MO) according to the manufacturer's guidelines. All data were processed by means of computer-supported analysis applying standard software (MetaSoft 3 Version: 3.9.9 SR5, Cortex, Leipzig, Germany).

VT_1 was determined as the first increase in ventilation between the first workload and 60% of P_{max} and VT_2 was determined as the second abrupt increase in ventilation between VT_1 and P_{max}. Calculations of turn points were performed by a computer-aided linear regression break point analysis (Hofmann et al., 2007). The athletes were fully familiarized with the use of this apparatus. Heart rate (HR) was recorded every 5 s during the test using a commercially available HR monitor (Polar RS 800, Polar Electro, Kempele, Finland). Power and stroke frequency were monitored and recorded continuously via computer display of the rowing ergometer.

Rowing performance

The maximal 2000-m all-out ergometer performance tests (MPT) were performed on a wind-resistance-braked rowing ergometer (Concept 2, Morrisville, VT, USA), with the resistant level set from 4 to 6. The rowing ergometer is one of the most used training equipments for rowers during the wintertime. During the MPT, athletes were asked to cover a distance of 2000-m in the shortest time possible. This MPT is part of the usual training preparation and athletes were familiar with the procedure. Power and stroke frequency were recorded continuously. The subjects performed MPT twice with at least 3 days of break between tests. Both MPT were preceded by a low intensity warm-up (MPT_{low}) but one test was preceded by an additional high intensity unspecific anaerobic upper body pre-load protocol (MPT_{high}). Both 2000-m MPT´s were performed in a randomized order to minimize the effect of test order. In the standard warm-up, rowers first performed 20 min of rowing at an intensity of 50% VO_{2max} measured during the incremental exercise test. 14 min after the warm-up, the rowers performed a maximal 2000-m ergometer all-out test as the standard procedure (Figure 1). The MPT_{high} was performed after the same 20 min warm-up, but added by a 25 s high intensity anaerobic upper-body all-out arm crank pre-load exercise (HIE) to induce an elevated systemic La concentration. Nine minutes of recovery was allowed after the maximal HIE before starting the MPT_{high} (Figure 1). The 25 s HIE was

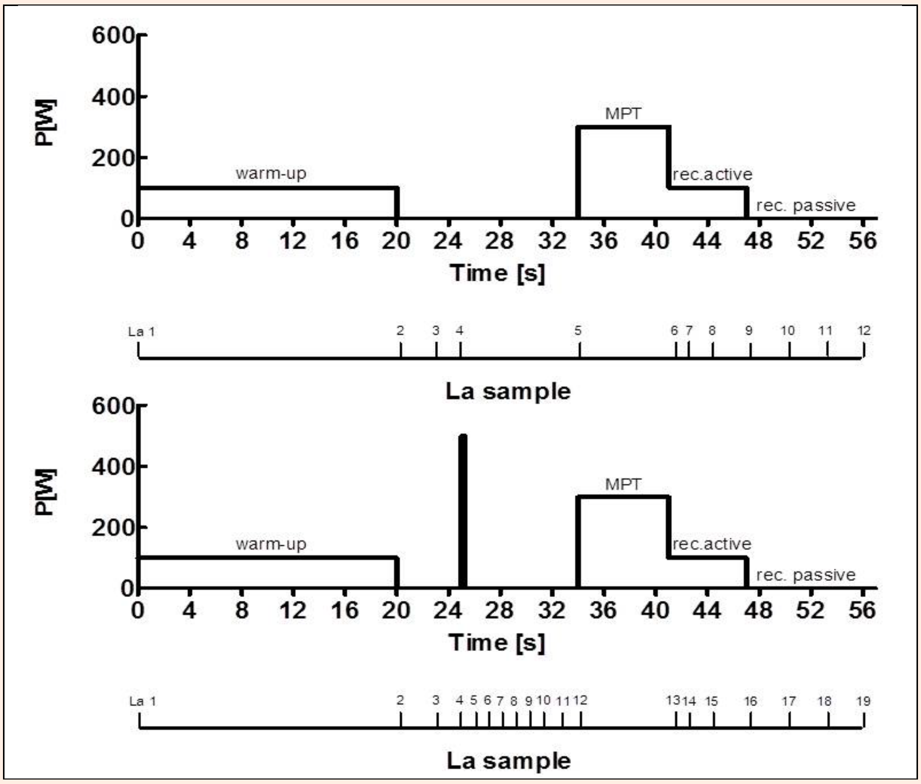

Figure 1. Different warm-up protocols for the 2000-m maximal performance test (MPT). Numbers in the upper row indicate time in min (t0-56) and numbers in the lower row (La1-19) indicate the number of blood samples to measure blood lactate concentration (La). The upper graph shows the low intensity warm-up (MPT_{low}) and the lower graph shows the additional high intensity pre-load (MPT_{high}).

performed on a Monark Ergomedic 849E (Sweden) arm bike with a brake weight of $30g.kg^{-1}$ body weight. From the beginning of the warm-up and during both MPT´s until the finish of recovery the subjects breathed through a facemask and respiratory variables were determined (Cortex MetaMax 3B, Germany).

La concentration was determined for both conditions at rest, after the warm-up, after the anaerobic-preload, and during recovery (Figure 1). La was measured by means of capillary samples (20µl) from an earlobe (Biosed S-line, EKF-Diagnostic, GER). Ear lobes were prepared by a salve to induce hyperemia (Finalgon forte®) Parallel to La measurements subjects were asked to evaluate their general and muscle fatigue using the 20 pt Borg scale (Borg, 1978).

Statistical analysis

All data were analysed using SPSS (version 20) (IBM, Armonk, NY, USA). For continuous variables, the distribution was tested by the Shapiro-Wilks method. To assess the difference in La, P, SR, HR, RER, VO_2, VCO_2 between the two MPT tests a 2-way repeated measures ANOVA test on both factors (test and time) was used. Mean differences were assessed by a independent t-test. Pearson correlation analysis was used to assess the relationships between 2000-m performance results variables and relevant gas-exchange and La concentration. Statistical significance was set at $p < 0.05$. All data are presented as mean ± standard deviation (SD).

Results

All nine subjects completed the incremental rowing ergometer test (Table 1) and two MPT tests (Table 2). Table 1 shows all relevant performance variables from the incremental exercise test. In brief, VO_{2max} was found at 56.67 ± 8.23 $ml·kg^{-1}·min^{-1}$ and P_{max} was 375.4 ± 44.0 W.

Table 1. Test characteristics from the maximal incremental rowing ergometer exercise test.

Subjects (n = 9)	Min	Max	Mean (±SD)
VO_2max ($l·min^{-1}$)	3.9	6.0	5.0 (.6)
VO_2max ($ml·min^{-1}·kg^{-1}$)	43.5	69.1	56.7 (8.1)
VE ($L·min^{-1}$)	173	218	194. 8 (13.9)
VT1 ($beats·min^{-1}$)	136	151	142.4 (5.0)
VT1 (W)	111	211	174. 6 (32.1)
VT2 ($beats·min^{-1}$)	161	180	170.2 (5. 9)
VT2 (W)	202	313	263.1 (34.0)
Pmax (W)	292	440	375.4 (44.0)
HRmax ($beats·min^{-1}$)	182	194	187.7 (4.3)

VO_{2max}- maximal oxygen consumption; VE- maximal ventilation; VT_1- first ventilatory threshold; VT_2- second ventilatory threshold; P_{max}- maximal aerobic power ; HR_{max} – maximal heart rate

Table 2. Results (n = 9) of a maximal 2000-m all-out rowing performance test (MPT) with low intensity warm up (MPT-low) and with additional high intensity 25 sec all-out arm crank pre-load (MPThigh). Data are means (±SD).

	MPTlow	MPThigh	Difference	p
Time (s)	401.7 (23.0)	405.4 (23.3)	3.7 (2.8)	.004
$Borg_{before}$	8.3 (1.7)	10.9 (1.9)	2.6 (1.7)	.002
$Borg_{after}$	18.3 (1.0)	18.1 (2.4)	-.2 (2.1)	.753

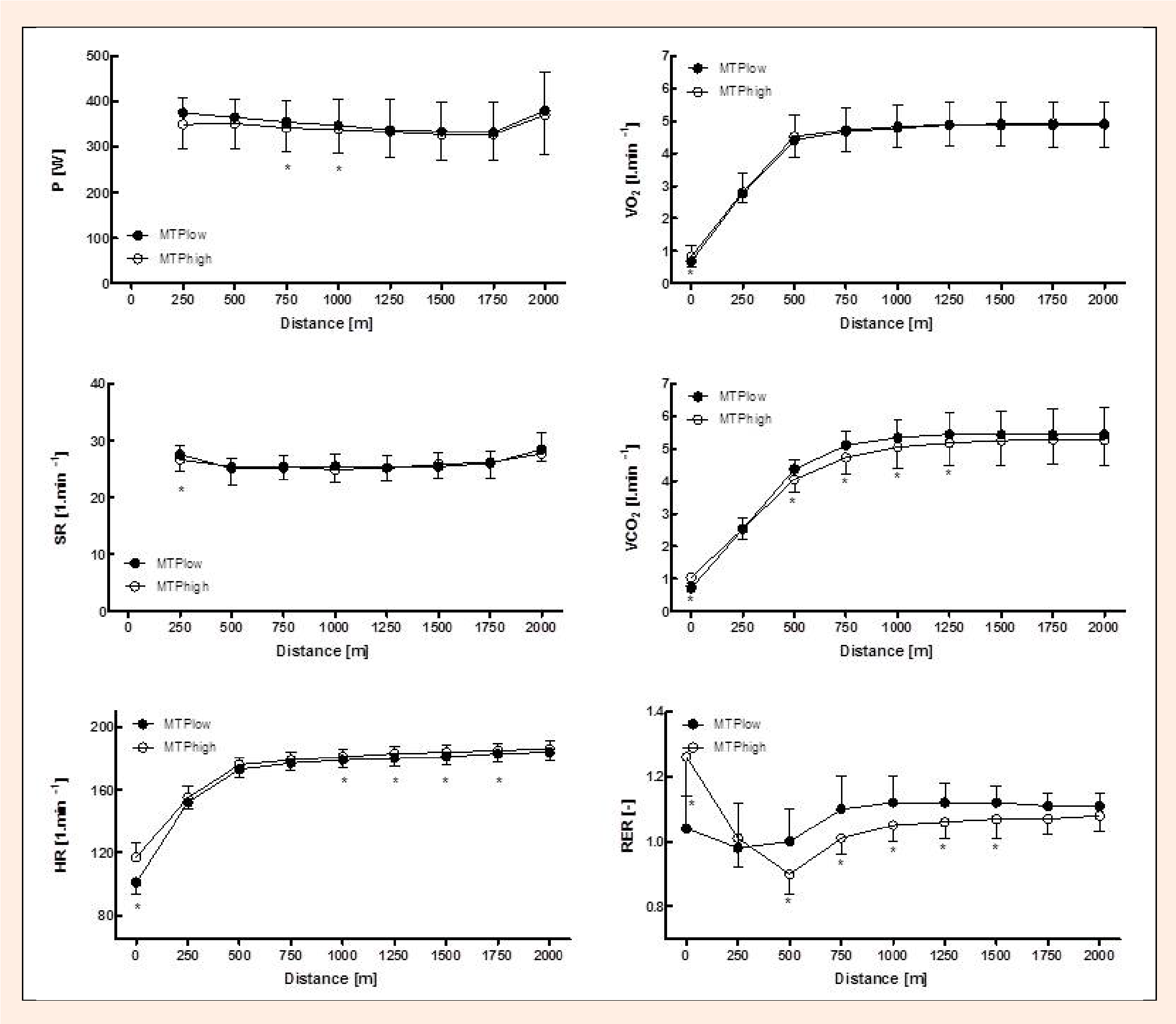

Figure 2. **The 2000-m all-out rowing performance test (MPT) split times, oxygen uptake (VO_2), carbon dioxide output (VCO_2),respiratory exchange ratio (RER), heart rate (HR), stroke rate (SR) and stroke power (P) after a usual low intensity warm up (MPT_{low}) and an additional 25 s all-out arm crank pre-load (HIE) (MPT_{high}).** * Significantly different from MPT_{low} ($p < 0.05$).

Table 3. **Blood Lactate concentration (mmol.l^{-1}) before and after a low intensity warm up, and before, after 3 minutes and 6 minutes of a maximal 2000-m rowing performance test. Data are means (±SD).**

	Before Warm-up	After Warm-up	After Warm-up 5 min	Before MPT	After MPT	After MPT 3 min	After MPT 6 min
MPT_{low}	1.4 (.2)	1.8 (1.2)	1.4 (.3)	1.2 (.6)	13.1 (2.7)	15.4 (2.1)	15.5 (2.5)
MPT_{high}	1.5 (.3)	2.0 (.8)	1.7 (.7)	8.42 (2.3) *	14.8 (1.7)	16.3 (1.8)	16.3 (2.4)
Difference	6.7%	10.0%	17.6%	85.7%	11.2%	5.2%	4.7%

MPT_{low}- Maximal 2000-m rowing performance test with normal low intensity warm-up; MPT_{high}- Maximal 2000-m rowing performance test with additional 25 sec all-out arm crank pre-load. Significantly different from MPTlow (p<0.05)

Rowing performance during MPT_{low} was significantly ($p = 0.002$) faster by 3.7 ± 2.8 s compared to the MPT_{high} condition (401.7 ± 23.0 s v. 405.4 ± 23.3 s). The first 1000-m of the MPT_{high} (Figure 2) were slower but not the second 1000-m whereas the 250-m split times of the first 1000-m were 0.6 to 1.1 s slower on average with the MPT_{high} conditions (Figure 2). VO_{2max} was not significantly different between the test conditions ($p = 0.248$), however, VCO_2 increase was significantly ($p = 0.025$) lower in the second, third, fourth and fifth 250-m split in the pre HIE performance test (Figure 2). VO_2 per W (economy) was higher in the HIE preload situation indicating a shift from anaerobic to a slightly higher aerobic energy contribution (Figure 2). RER was significantly increased at the start of the MPT_{high} ($p = 0.001$) due to the anaerobic pre-load, was similar at 250 m and was significantly lower at 500 m ($p = 0.004$), 1000 m ($p = 0.003$) and 1500 m ($p = 0.031$) of rowing. RER of the last 500 meters was lower im MPT_{high} but this difference was not significant ($p = 0.168$).

La concentrations after the low intensity warm-up were not significantly different ($p = 0.839$) between the tests (Table 3). The 25 s HIE (Figure 1) was performed with an averge power (P_{avg}) of 302.4 ± 47.2 W (3.4 ± 0.6

W·kg^{-1}) which increased La significantly before the MPT (La_{before}: 8.4 ± 2.3 mmol.l^{-1}) in MPT_{high} compared to 1.2 ± 0.6 mmol·l^{-1} in MPT_{low} test. Both MPT´s significantly increased La (La_{after}) which was significantly (p = 0.042) higher in MPT_{high} (14.8 ± 1.7 mmol·l^{-1}) compared to MPT_{low} (13.1 ± 2.6 mmol·l^{-1}) (Table 3). Net La increase from the start to the end of the MPT_{low} was 11.9 ± 2.3 mmol·l^{-1} (Figure 3) which was significantly greater compared to MPT_{high}. High-intensity arm exercise elevated La_{before} up to 8.4 ± 2.3 mmol·l^{-1} (Table 3) but La_{max} after higher in MPT_{high} (14.8 ± 1.7 mmol·l^{-1}) compared to MPT_{low} (13.1 ± 2.6 mmol·l^{-1}) (Table 3). Net La increase from the start to the end of the MPT_{low} was 11.9 ± 2.3 mmol·l^{-1} (Figure 3) which was significantly greater compared to MPT_{high}. High-intensity arm exercise elevated La_{before} up to 8.4 ± 2.3 mmol·l^{-1} (Table 3.) but La_{max} after the MPT was just slighly higher than without pre HIE (p > 0.05; Table 3). Net La increase was significantly reduced to 6.3 ± 1.8 mmol·l^{-1} (53.3%) in MPT_{high} (Figure 3) but La dynamics during recovery were similar in both conditions.

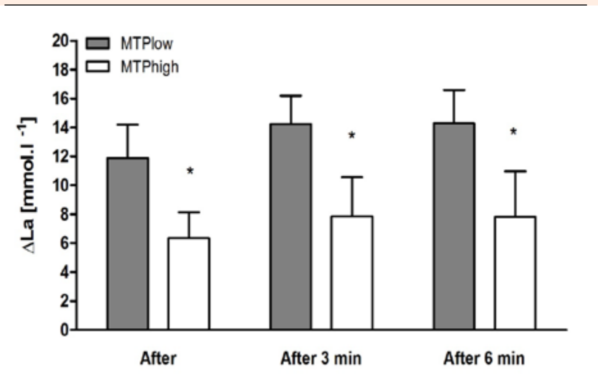

Figure 3. Changes of blood lactate concentration from pre to post exercise, as well as from pre to 3 min and 6 min post exercise in a maximal 2000-m all-out rowing performance test with normal low intensity (MPT_{low}) and with additional 25 sec all-out arm crank pre-load exercise (MPT_{high}). * Significantly different from MPT_{low} ($p < 0.05$).

HR was significantly higher in MPT_{high} at the start (p = 0.001) and also significantly different (p = 0.001) throughout the 2000 m all-out rowing. Stroke rate was significantly lower durnig the first 250 m in MPT_{high} (p = 0.021) but not significantly different (p = 0.501)) for the rest of the 2000 m all-out rowing.

Ratings of percieved exertion at the start ($Borg_{before}$) were significantly (p = 0.002) lower in MPT_{low} compared to MPT_{high} but not significantly different after both MPT´s (p = 0.753) (Table 2).

MPT time was significantly correlated to VO_{2max} from the incremental ergometer test (r = -0.83), VT_1 (r = -0.95), VT_2 (r = -0.93), and P_{max} (r = -0.95). The difference between MPT_{low} and MPT_{high} performance times was significantly related to Labefore (r = 0.71) and La_{after} (r = 0.68) in MPT_{high}. La_{before} in MPT_{high} was significantly related to hand ergometer HIE performance $P_{max/kg}$ (r = 0.78), $P_{avg/kg}$ (r = 0.79) and to the difference between PT times (r = 0.71).

Discussion

The main finding of the study was that the high-intensity non-specific anaerobic pre-load slightly but significantly decreased the 2000-m rowing ergometer performance by 1% but substantially reduced the glycolytic energy contribution. . The decrease in performance was only significant for the first 1000-m of the MPT_{high} although the same oxygen uptake at the start was found for both tests. Oxygen uptake was neither accelerated nor increased in the pre-loaded MPT_{high} condition. The decreased performance in MPT_{high} was related to a lower stroke rate and a reduced anaerobic energy contribution, indicated by the marked decrease in net lactate concentration, CO_2 output and RER during the maximal all out performance test.

Different from other endurance events, rowing is a strength-endurance type of sport involving approximately 70% of the whole body muscle mass (Steinacker et al. 1993). The 2000-m performance distance in on-water rowing has considerable stress on energy systems for about 67% is considered aerobic and 33% anaerobic metabolism (Mäestu et a., 2005; Steinacker et al., 1993) which can be simulated by a six minutes workout (Hartmann ja Mester, 2000) or 2000 metre rowing ergometer race (Jürimäe et al., 2000). As expected from the literature, we found a statistically significant correlation between the 2000-m ergometer performance time and Pmax (r = -0.95) and VO_{2max} (r = -0.83) in our study indicating the overall importance of a high maximal absolute power output and oxygen uptake (Mäestu et a., 2005) Besides high oxygen uptake during the main part of the a race an additional critical part of a successful rowing competition is a fast start utilizing high anaerobic power (Garland, 2005). Although muscle metabolites have not been measured in detail, for rowing exercise, there is evidence that the relatively long duration exercise at an intensity close to maximal oxygen uptake will decrease phosphocreatine stores and increase muscle lactate levels substantially (Mavrommataki et al. 2006). This high-intensity anaerobic start quickly increases muscle and La concentration and decreases pH already in the first minute of a 6-8 min race if initial La concentration is low. It could be argued that it might be beneficial to avoid the side effects of this rapid pH and La changes early after the start of a race within the rowing specific muscles. It has been shown recently that not extracellular acidosis (pHe) but intracellular acidosis (pHi) is responsible for muscle fatigue and performance limitations. Even though reports of a beneficial effect of metabolic acidosis on force development in isolated rat muscle have challenged this view (Volianitis et al., 2010). As shown in our study and by others (Bogdanis et al. 1994) a systemic increase in blood La by non-dominant muscles inhibits glycolysis and substantially decreases net muscle lactate production due to an inverted gradient for La. It is suggested that this decreased La production favors oxidative metabolism, which was not found in our study. However, we suggest that subjects applied their same pacing strategy as usual but possibly could have tried harder during the first minute of exercise. Pacing strategy is therefore important, not to lose too much time at the start and to avoid severe side effects limiting the rest of the race (Gee et al., 2013). Currently, pacing is more or less the same in all rowers, starting fast and trying to sustain the high La concentration induced by the start for the rest of the race. As it was shown that pre-elevation of systemic La levels by non-specific muscle exercise inhibited subsequent net La increases (indicating an inhibition of muscular lactate production) it might be suggested that this effect may also be applied in maximal rowing exercise (Müller et al., 2013). Two main effects may be expected such as a decrease in anaerobic energy contribution during the first min of a race and an increase in oxidative energy contribution. In our study maximal La concentration was 15.4 ± 2.1 mmol·l^{-1} after the 2000-m MPT_{low}, and 16.3 ± 2.4 mmol·l^{-1} in MPT_{high} which is comparable to the results of our previous studies (Mäestu et al., 2005). Mäestu et al. (2000) reported La values three minutes after 2500-m rowing ergometer race at 17.0 mmol·l^{-1} in lightweight and at 16.5 mmol·l^{-1} in heavyweight rowers comparable to values obtained after a 2000-m on-water single scull race (16. 0 mmol·l^{-1}).

Rowers performing the HIE pre-load had higher La values at the beginning of the MPT, which significantly diminished the increase in net La concentration and lactic anaerobic energy contribution. This was in line with a significant reduction in VCO_2 with pre HIE (see Figure 3) indicating an inhibition of La production. The net increase in La concentration during MPT_{high} was 53% lower than during MPT_{low}. In line with findings by Bogdanis et al. (1994) we could show that the elevation of La concentration by high intensity non-specific arm exercise significantly inhibited net La accumulation and rowing at maximal work load applied to the subjects was slightly but significantly slower (Figure 2). This implies that high intensity anaerobic pre-load exercise too close to a specific competition workout may limit maximal anaerobic exercise contribution and sports performance as long as a maximal anaerobic lactate production rate such as in sprint exercise is required (Bishop, 2003; Bishop et al., 2001; Iaia et al., 2010; Parolin et al., 1999). As rowing does not require a maximal sprint at the start it might be speculated that although anaerobic energy contribution is reduced this may be compensated by an increased oxidation rate. Our results did show neither a significant priming effect nor an increased oxygen uptake at peak exercise questioning these effects. On the other hand, the clear reduction of net La production was just accompanied by a rather small reduction in overall performance lower than 1 %. This increase in split times was only significant for the first 1000 m, which might be attributed to racing strategy influenced by the pre-load situation. Subjects might believe that the anaerobic pre-load will not allow starting with the same speed, which may be a major confounder. The capacity of substrate-level phosphorylation should not be a limit as it was suggested to be completely restored 10 min after heavy-intensity priming exercise (Burnley et al., 2011). In support of our hypothesis, it was also shown by Bogdanis et al. (1994) and Müller at al. (2013) that peak and mean power output were not significantly reduced if La elevation was induced by a non specific muscle group which indeed is difficult to perform in rowing as it is a whole body all out exercise (Mäestu et al., 2005).

The results of our study demonstrate that performance time was 3-4 s faster in MPT_{low} compared to MPT_{high} (see Table 2). The reason for this could be the fact that the HIE warm-up was performed by the arms which were also significantly involved during rowing or the pre-load intensity was too high and/or too close to the all-out exercise. Burnley et al. (2011) reported also that the 10-min recovery after heavy-intensity priming might have been too short to allow the priming effects. These authors concluded that prior heavy exercise increased the primary VO_2 amplitude and increased the tolerable duration of severe exercise performed after 10 min of recovery. This was associated with a significant increase in power. The effect on exercise performance was positive after prior heavy-intensity priming and neutral after prior severe-intensity priming. More prolonged recovery intervals may produce more consistent performance effects (Burnley et al., 2011). It has previously been shown that if the warm-up intensity is too high, the subsequent metabolic acidaemia is associated with impaired supramaximal performance and a reduction in the accumulated oxygen deficit (Bishop et al. 2011). In support to our study Bailey et al. (2009) showed, that heavy-intensity pre-load did not elicit the typical pre-load exercise effect on the VO_2 response during subsequent exercise when recovery exceeded 9 min. The results of Bishop et al. (2001) demonstrated that when the rest period after the first performance was fixed, it could have a significant influence on subsequent performance. An additional explanation for the reduction in performance in our study is suggested to be the usual pacing strategy that obviously was not changed in the HIE pre-load condition. HIE, inducing a La concentration of about 8-10 mmol.l^{-1} may lead to a more careful start knowing about the already elevated La concentration. As the differences in workload could not be blinded to the subjects in our study, we cannot rule out such an effect. As La production will be limited both in arms and legs with the HIE pre-load subjects might be able to start at the same or even a higher pace (eg. with the legs) but did not do so because of fear to overreach. Additional studies applying only split distances may give some more detailed insight into the limits of the approach. Even if maximal race performance is limited by such an HIE pre-load, the approach may be interesting for training situations forcing a higher aerobic energy contribution by inhibiting La production (Müller et al., 2013) although not seen in our study.

In addition to the energetic effects, neuromuscular effects of the pre-elevated La induced by non-sport specific muscle groups may be expected due to the lower intra-muscular La accumulation which is suggested to be the main interesting effect for high-intensity, technically oriented sports. Unfortunately, the ergometer MPT did not allow proving this assumption in our study but it is rather difficult to prove this hypothesis on water due to the variable conditions. A blunted anaerobic energy contribution was shown by Layec et. al., (2009) to reduce strain on the neuromuscular system, which may lead to better neuromuscular conditions. These authors (Layec et al. 2009) suggested that a greater oxidative ATP production reduce metabolic strain per fibre and this effect could be an advantage in high intensity (sub-maximal) sports with high technical demands such as on-water rowing.

Pre-exercise blood La concentration and the performance time as a result of MPT_{high} were not significantly related. The difference between MPT_{low} and MPT_{high} performance times was significantly related to Labefore (r = 0.71) and La_{after} (r = 0.68) in MPT_{high}. However, we found a significant relationship between blood La before MPT_{high} and the arm crank ergometer HIE performed $P_{max/kg}$ and $P_{avg/kg}$. This implies that if the athletes performed high arm crank ergometer HIE results, the higher the concentration of the pre-exercise blood La was.

Previous studies used arm exercises as a HIE preload to induce a systemic elevation of blood La and the subsequent performance was done by leg muscles only (Bogdanis et al., 1994; Müller et al., 2013). Our study included rowers using both arms and legs, which might limit the application to submaximal training effects. Accordingly, the increased La concentration as a result of HIE pre-load had small but negative consequences for overall performance in the MPT in our study. In addition, as rowers utilise both arm and leg muscles, the lactate values of 8.4±2.3 $mmol.l^{-1}$ before MPT are suggested too high as shown by Burnley et al. (2011). Our participants performed MPT_{high} slower in the first 1000-m (see Table 2). As we increased La with the arms in the HIE pre-load, fatigue might remain evident until the start of the MPT indicating that the time to the start may be also an important factor which should be investigated systematically. With that pre-load at the start, rowers possibly did not feel ready to perform their maximum as in normal conditions characterized also by higher Borg scale results in the HIE pre-load test. Interestingly, the rowers were able to perform the second 1000-m of the MPT with same split times indicating a limit at the start but not for the rest of the workout, which was performed at the same RPE.

It can be argued that applying the same pacing strategy with different starting conditions may have led to the decrease in performance. We suggest that the reduced net La production with a higher oxygen uptake per W may allow a faster or longer start sprint. Pacing strategy should therefore be adapted in future experiments (Gee et al., 2013).

Conclusion

In summary, the HIE pre-load added to a standard low intensity warm-up protocol failed to improve performance but opens some other interesting questions regarding the optimal preparation before a high intensity all-out workout. Additional studies are needed before any conclusions can be drawn. Future studies should focus on different HIE pre-load conditions such as performing only leg pre-load, lower La induction, or different pacing strategies.

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Key points

- As blood lactate production can be inhibited to some extent, oxidative metabolism is favored which might be beneficial in some specific training sessions aiming to improve aerobic power.
- Despite a reduced performance in the 2000-m all out rowing in MPT_{high} the results offer some interesting information for physiology and training in top-level rowers.
- Applying this concept might allow a different pacing of competitions. Additional investigations are needed to elucidate possible beneficial effects.

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