

Physiological analysis of the 100 km indoor rowing World Record

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Abstract:

The aim of the study was to analyze the rowing ultra-endurance race where the 100 km Mixed Tandem World Record was broken. The team consisted of one female athlete (age: 32 years; body mass: 61.5 kg; height: 174 cm) who won the 2016 World Championship and one male athlete (age: 40 years; body mass: 74 kg; height: 179 cm), third classified of the same competition. Heart Rate (HR) was monitored with two heart rate sensors Polar H7 Bluetooth Smart and lactic acid was measured with Lactate Pro TM2 analyzer. The *z* Test was calculated for comparison of proportions based on the quotient that results from dividing effects errors. To analyze HR response, six different HR zones were determined as a function of each player's maximal HR (HR_{max}): Z1: <60%; Z2: 61–70%; Z3: 71–80%; Z4: 81–90%; Z5: 91–95%, and Z6: >95%. Three different exercise intensities were defined as percentages of HR_{max} : low intensity: <70%, moderate intensity: 70–90% and high intensity: >90%. Athletes complete the race in 6:20:52.9 (hh:mm:ss.d) performing alternating relays every two minutes of execution and rest. Results showed that subject 1 spent more time in Z4 (35.56%, $p<0.01$) and in Z2 (21.26%, $p<0.05$) and the highest percentage of time was at moderate intensity (51.85%, $p<0.05$). Predominant work zones of subject 2 were Z1 (19.64%, $p<0.05$), Z4 (21.38%, $p<0.05$) and Z5 (22.15%, $p<0.05$) and the highest percentage of time was at high intensity (42.27%, $p<0.001$). Lactate concentration of subject 1 and 2 reached a mean of 3.9 ± 5.1 and 5.1 ± 1.3 mmol/l mmol/l, respectively. These findings can help in the preparation of future ultra-endurance races and in the planning of strategies when this type of tests are for relays.

Key words: hear rate, lactate, ultra-endurance, performance.

Introduction

Physiological demands in rowing have been widely analyzed in scientific literature. Competitive rowing distance consists of covering 2000 m in 6 to 8 minutes (de Campos Mello, de Moraes Bertuzzi, Grangeiro, & Franchini, 2009; Volianitis & Secher, 2009) depending on boat type and environmental conditions (Smith & Hopkins, 2012). Rowing requires a high aerobic and anaerobic capacity (Akça, 2014), with aerobic metabolism predominating in a 67% and the remaining 33% contributing by anaerobically, 21% alactic and 12% lactic. Blood lactate concentration oscillates between 4 and 8 mmol/l (Mäestu, Jürimäe, & Jürimäe, 2005). The short duration in competition of this sport and the high intensity varies the oxygen volume from 75% to even more than 100% (Russell, Le Rossignol, & Sparrow, 1998). Hagerman & Hagerman, (1990) and Yoshiga & Higuchi (2003) showed that the maximum oxygen consumption was around 6 liters per minute.

On the other hand, rowing training is characterized by low intensity and long duration (Ingham, Carter, Whyte, & Doust, 2008). The volume of training that rowers perform is considerably high since they usually train 6 days a week (Greene, Sinclair, Dickson, Colloud, & Smith, 2009) and between 10 and 12 weekly training sessions (Bourgeois, Steyaert, & Boone, 2014). Training volume has shown to correlate significantly with rowing performance (Penichet-Tomas, Pueo, & Jimenez-Olmedo, 2016). Eighteen-year-old rowers typically spend 52-55% of training time rowing in water, twenty-one-year-old rowers usually spend 55-60% of the annual time, and rowers for more than twenty-one years old more than 65% of the time (Battista, Pivarnik, Dummer, Sauer, & Malina, 2007). However, in many cases, bad weather conditions can cause rowers not to train in water so indoor rowing become very important in training (Akça, 2014).

Most research that focuses on the physiological responses of rowers at the competition distance of 2000 m is carried out indoor on a rowing ergometer. De Campos Mello et al. (2009) compared energy system contributions of rowers in three different conditions: rowing on ergometer without and with the slide and rowing in water. Results showed that the time in water was longer and metabolic work was significantly greater than during ergometer and ergometer with slides. However, the volume of oxygen, the heart rate and the lactate concentration were not different between these different conditions. Other articles compared the variation of heart rate with training of different intensities (Vaz, Picanço, & Del Vecchio, 2014). This study concluded that

polarized training is a better option for these athletes because they recover in less time than with long-term aerobic training.

Although the different types of ergometer are a fundamental tool in training of rowers, the differences between performance profiles in ergometer and water and the difference of performance requirements to obtain a good ergometer result have promoted the ergometer to be considered as its own sport. Currently, there are national and international competitions where rowers, CrossFit athletes and other different athletes compete in this sport. In addition, the last edition of the World Games (2016) was the first time in which indoor rowing was included as a discipline. Also, these competitions are not only carried out over distances of 2000 or 6000 m as it happens in Olympic rowing, but there are also ultra-endurance competitions.

Zaryski & Smith (2005) defined the ultra-endurance competitions as those that last at least 6 hours. Ultra-endurance competitions have been the subject of study over the years in various sports. Cycling has been one of the sports analyzed during tests lasting at least 24 hours. Neumayr, Pfister, Mitterbauer, Maurer, & Hoertnagl (2004) described heart rate responses during a 24 hour test where athletes maintained a moderate intensity during the test. In addition, they suggested the ultra-resistance threshold just below 70% of HR_{max} . However, in the tests carried out in relays, the average intensity was higher, about 85 to 90% of HR_{max} (Bescós et al., 2011). Mountain ultra-marathons have also been analyzed in recent years (Fornasiero et al., 2018; Mrakic-Sposta et al., 2015). The average intensity that the athletes carried in The second edition of Vigolana Trail was approximately 77% of HR_{max} and most of the race time they were working at intensity below VT1 (Fornasiero et al., 2018). In rowing, the tests considered as ultra-distance are at least 100 km or 24 hours long. However, its importance, there is no scientific evidence from studies that have analyzed the physiological demands in ultra-distance rowing tests. The objective of the present study was to analyze the rowing ultra-endurance race where the 100 km Mixed Tandem World Record was broken.

Material & methods

Participants

The sample of the case study is composed of two subjects who obtained the 100 km indoor rowing World Record during the study data collection, and which they still hold today. Subject one was the female athlete who won the 2016 World Indoor Rowing Championship (Boston, USA), 32 years old, body mass 61.5 kg and height 174 cm. Subject two was the male athlete who was third classified of the same competition, 40 years old, weight 74 kg and height 179 cm (Table 1). The participants were informed of the experimental protocol and gave their written informed consent the day before.

Procedure

The test began at 08:00 AM and consisted of covering 100,000 m in the shortest possible time. The two subjects had to perform the test alternating to row continuously in the same rowing machine. The strategy used by the team was to conduct two-minute series, with two minutes of rest between sets, at sub-maximum intensity. Environmental conditions recorded during the test resulted in average temperature of 23.9 °C and average relative humidity of 61%. The test was performed on an ergometer Concept 2 model D (Hoffmann, Filippeschi, Ruffaldi, & Bardy, 2014) adjusted with drag factor 115 and examined through PM5 monitor (Maciejewski, Messonnier, Moyon, & Bourdin, 2007). Heart rate was monitored with two heart rate sensors Polar H7 Bluetooth Smart connected to two heart rate monitors Polar M400 (Sempf, Brahms, & Thienes, 2016), to store the heart rate per second, and an iPad with the Polar Team app v.1.1, for visualization and control for athletes and coaches. The Lactate Pro TM2 analyzer was used to measure the lactic acid extracted every twenty minutes (Baldari et al., 2009). This device has the LOD enzyme electrode method measurement principle and has a measuring range of 0.5–25.0 mmol/l (5–225 mg/dl). All measurements were made with the Lactate Pro 2 test strips. In order to establish a reference for heart rate zones we determined zone 1: <60% HR_{max} , zone 2: 61–70% HR_{max} , zone 3: 71–80% HR_{max} , zone 4: 81–90% HR_{max} , zone 5: 91–95% HR_{max} , and zone 6: >95% (Pueo, Jiménez-Olmedo, Penichet-Tomás, Ortega Becerra, & Espina Agulló, 2017). Exercise intensity as expressed into three zones: low intensity (<70% HR_{max}), moderate intensity (70–90% HR_{max}) and high intensity (>90% HR_{max}) (Fornasiero et al., 2018; Neumayr et al., 2004). The maximum heart rate was estimated using the formula proposed by Tanaka, Monahan, and Seals (2001).

Statistical analysis

The relation of the z Test was calculated for the comparison of proportions based on the quotient that results from dividing effects errors. The effect will be the difference between the two proportions and the error will be the standard error of the difference between proportions (SEDP). The variance of a difference is equal to the sum of the variances of each part of the difference. Therefore, the standard error of a difference will be the square root of the sum of the variances divided, each, by the size of the respective sample (n_1 , n_2). From each group, the overall proportion p is used, and n_0 the proportions (p_1 and p_2),

$$z = \frac{p_1 - p_2}{\sqrt{\frac{p \cdot q}{n_1} + \frac{p \cdot q}{n_2}}}$$

where p_1 is the proportion of events observed in a group; p_2 is the proportion of events in the other group; p is the total (or marginal) proportion for both groups together; q is the complementary of p ; n_1 is the number of frequencies of the first group and n_2 is the number of frequencies of the other group.

The standard normal distribution of the z value was calculated to obtain the p value of the z test. The confidence interval of the difference in proportions was obtained first by means of the absolute difference between the proportions of the sample $|d|$ (whereas for a 95% confidence interval, $z^{\alpha/2}$ would be 1.96). Finally, the confidence interval of the difference in proportions was calculated, adding for the upper limit and subtracting for the lower limit the value of z times that of SEDP to the absolute difference.

Results

The mixed tandem 100 km indoor rowing World Record was beaten in 06:20:52.9 (hh:mm:ss.d) with average speed of 1:54.3 min/500m. Subject 1 showed heart rate of 142.03 ± 24.18 bpm (mean \pm SD), lactate concentration of 3.92 ± 0.77 mmol/l and 5.7 mmol/l peak value. On the other hand, subject 2 reached heart rate of 144.74 ± 30.63 bpm and lactate concentration of 5.06 ± 1.30 mmol/l with 8.6 mmol/l as peak value.

Table 1: Descriptive data.

	Subject 1	Subject 2
Age (years)	32	40
Height (cm)	174	179
Body mass (kg)	61.5	74
BMI (kg/m ²)	20.3	23.1
HR _{max} (bpm)	185	180
HR _{mean} (bpm)	142.0	144.7
SD HR _{mean} (bpm)	24.2	30.6
La _{max} (mmol/l)	5.7	8.6
La _{mean} (mmol/l)	3.9	5.1
SD La _{mean} (mmol/l)	0.8	1.3

HR: heart rate; SD: standard deviation;
bpm: beats per minute; La: lactate.

The comparative response of heart rate between subjects shown in Table 2 demonstrates the zone in which subject 1 has spent more time was Z4 with 135.45 minutes. However, subject 2 showed a more distributed heart rate pattern across zones, where Z5 was the zone with maximum value, 84.37 minutes. On the contrary, the zone where subject 1 and 2 have spent less time were Z6 with 0.30 minutes and Z2 with 44.17 minutes, respectively. There were significant differences in the percentage of time that subject 1 has spent in Z4 (35.56%, $p < 0.001$; 160.35 ± 5.19 bpm) and in Z2 (21.26%, $p < 0.001$; 119.73 ± 5.69 bpm). However, subject 1 has only spent 21.38% of time in Z4 and 11.60% of time in Z2. On the other hand, subject 2 was working significantly longer in Z5 (22.15%, $p = 0.005$; 167.79 ± 2.62 bpm), Z1 (19.62%, $p = 0.019$; 92.32 ± 9.64 bpm), and Z6 (12.25%, $p < 0.001$; 175.88 ± 3.20 bpm). The percentage of time that subject 1 spent working in these areas has been 14.27% in Z5, 13.34% in Z1 and 0.08% in Z6. No significant differences were found between time spans that subjects spent in Z3.

Table 2: Comparison of time proportions by HR zone and exercise intensity between subjects.

		HR _{max} (%)	Subject 1			Subject 2			Comparison of time proportions		
			Time (min)	Time (%)	HR _{mean} (bpm)	Time (min)	Time (%)	HR _{mean} (bpm)	CI 95%	CI 95%	p
HR zone	Z1	< 60	50.80	13.34	101.58 ± 7.30	74.75	19.62	92.32 ± 9.64	-0.115	-0.010	0.019
	Z2	60-70	80.98	21.26	119.73 ± 5.69	44.17	11.60	116.65 ± 5.57	0.044	0.149	<0.001
	Z3	71-80	59.02	15.49	139.49 ± 5.15	49.52	13.00	135.64 ± 5.15	-0.025	0.075	0.325
	Z4	81-90	135.43	35.56	160.35 ± 5.19	81.45	21.38	154.39 ± 5.29	0.078	0.205	<0.001
	Z5	91-95	54.37	14.27	169.95 ± 1.72	84.37	22.15	167.79 ± 2.62	-0.133	-0.024	0.005
	Z6	> 95	0.30	0.08	176.84 ± 0.85	46.65	12.25	175.88 ± 3.20	-0.155	-0.089	<0.001
Exercise intensity	Low	< 70	128.73	33.80	112.33 ± 10.68	106.23	27.89	92.32 ± 9.64	-0.006	0.125	0.078
	Moderate	70-90	197.50	51.85	153.65 ± 11.21	113.67	29.84	137.75 ± 16.47	0.152	0.288	<0.001
	High	> 90	54.67	14.35	170.02 ± 1.85	161.00	42.27	172.29 ± 4.99	-0.340	-0.218	<0.001

HR: heart rate; HR_{max}: maximum heart rate; Z1-Z6: HR zones 1 to 6.

The distribution of exercise intensity is divided into low, moderate and high thresholds. During the test, exercise intensity distribution of subject 1 was 51.85% in moderate intensity, 33.80% in low intensity and 14.35% in high intensity. On the other hand, subject 2 was more time in high intensity, 42.27%, followed by 29.84% in moderate intensity and 27.89% in low intensity. Subject 1 has spent significantly ($p < 0.001$) more time at moderate intensity than subject 2. However, subject 2 has spent significantly ($p < 0.001$) more time at high

intensity than subject 1. No significant differences were found between time spans that subjects spent at low intensity.

The comparison of time zones of each subject is reported in Figure 1 (A1-A2). Significant differences were observed between the time that subject 1 was in Z4 (35.56%, $p<0.01$) and in Z2 (21.26%, $p<0.05$) in comparison to the remainder zones. Similarly, the time that subject 2 was in Z1 (19.64%), Z4 (21.38%) and Z5 (22.15%) was significantly higher ($p<0.05$) than the time spent in the remainder zones. Figure 1 (B1-B2) compares the time each subject spent at different intensities. Significant differences were found in the time that subject 1 was working at moderate intensity (51.85%, $p<0.05$) respect to low (33.80%) and high intensity (14.35%). In addition, significant differences ($p<0.05$) were also found between time spent at low and high intensities. Finally, subject 2 worked significantly more time at high intensity (42.27%, $p<0.001$) than at low intensity (27.89%) and moderate intensity (29.84%).

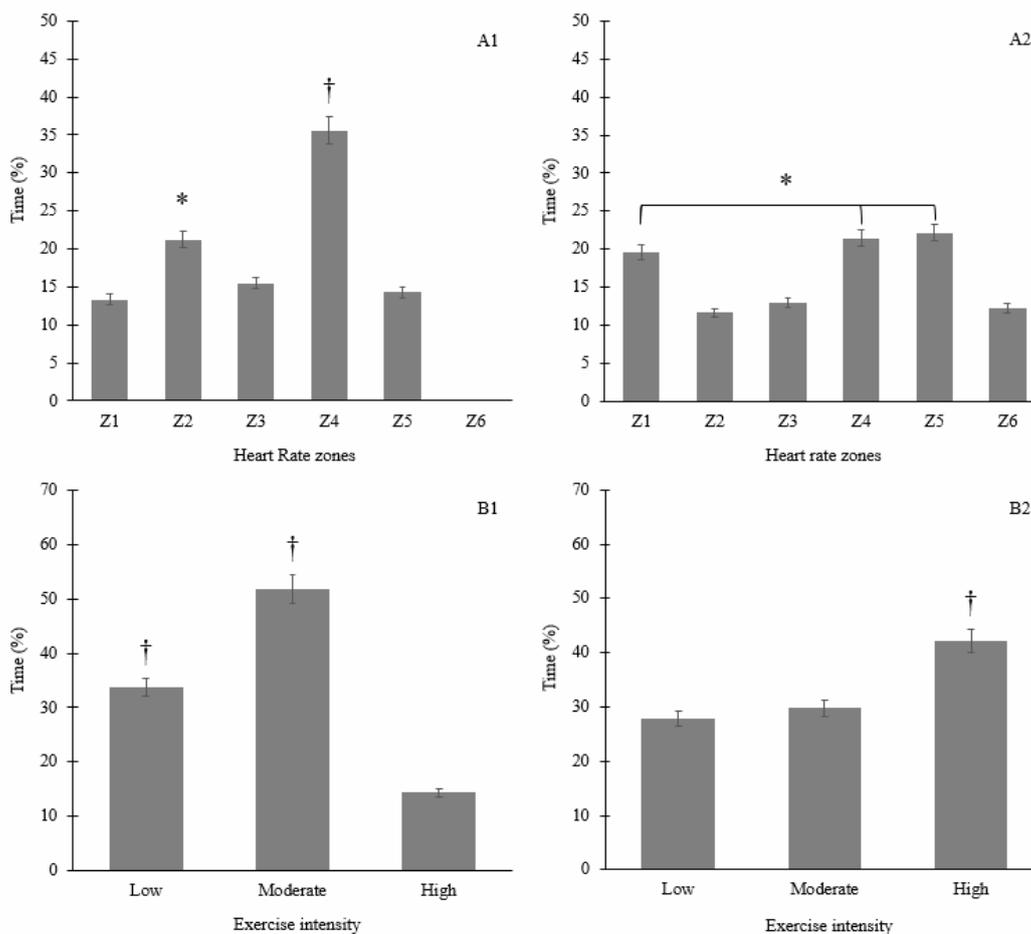


Fig. 1: Comparison of time proportions by HR zone and exercise intensity of each subject.

* $p<0.05$; † $p<0.01$; A1-B1: subject 1; A2-B2: subject 2.

Discussion

This study is the first to analyze the heart rate response in an ultra-resistance rowing test. Results have shown that the average heart rate of the subjects was 142.03 ± 24.18 bpm (subject 1) and 144.74 ± 30.63 bpm. These data agree with the average heart rate of ultra-resistance runners in the study of Jastrzbski, Zychowska, Radziminski, Konieczna, & Kortas (2015) which reached an average heart rate of 143.25 ± 4.65 bpm during a 100 km run. However, the athletes who made the Castle of Cartagena Race, with a distance of 54 km, reached a higher average with 158.8 ± 17.7 bpm (Ramos-Campo et al., 2016). Although the duration in this last race was closer to the duration of the World Record (between 6 and 7 h) and less than the study of Jastrzbski et al. (2015) (between 9 and 12 h) they obtained a greater heart rate surely due to the unevenness of the test to be a race for mountain, demanding a greater physiological demand.

The mean blood lactate concentrations of the subjects of the present study were 3.92 ± 0.77 mmol/l and 5.06 ± 1.30 mmol/l with a maximum peak of 5.7 mmol/l and 8.6 mmol/l (subjects 1 and 2, respectively). Mean values of lactate concentration in the corridors of the race by relay of ultra-resistance of 24 h (Clemente, Munoz, Ramos, Navarro, & Gonzlez-Rav, 2010) were very similar with an average concentration of 4.13 ± 1.03 mmol/l. On the other hand, peak concentration values of lactate were 5.3 ± 2.4 mmol/l, slightly higher than

subject 1 of the present study, but much lower than subject 2. However, although the runners of Ramos-Campo et al. (2016) study carried a higher intensity, they did not reach the lactate concentration of the present study. The type of test may have influenced lactate concentration levels since the present study was conducted by two-minute relays with a two-minute break while the ultra-endurance mountain-event was continuous. The lactate peak of subject 2 of the present study reaches such high values because it was him who made the final stretch of the test.

Subject 1 of the present study was the highest percentage of time in Z4 (81-90% of HR_{max}) with 135.43 min (35.56% of total time). On the other hand, subject 2 spent more time in Z4 and in Z5 (91-95% of HR_{max}) with 21.28% and 22.15% respectively, adding a total time of 165.82 min. These data are very close to Bescós et al. (2011), where ultra-endurance relay race cyclists achieved an average value of $87 \pm 3\%$ HR_{max} (team of four) and $87 \pm 1\%$ HR_{max} (team of six). In studies where the race duration has been longer than 6-7 hours with no relays, the predominant heart rate zones have been below 70% of HR_{max} (Neumayr et al., 2004).

Race intensity of subject 1 was moderate (70-90% HR_{max}) during the 51.85% of time (197.50 min). This result agrees with Bescós et al. (2011), whose athletes were also in the same intensity range. The second most spent intensity zone by subject 1 was low intensity zone (<70% HR_{max}) with 33.80% of time. However, this low intensity zone was the most spent by athletes of studies addressing greater duration races. The runners in Fornasiero et al., (2018) spent $85.7 \pm 19.4\%$ of time at low intensity while at moderate and low intensity, they spent $13.9 \pm 18.6\%$ and only $0.4 \pm 0.9\%$ of time, respectively. In Neumayr et al. (2004), cyclists spent 53% of time at low intensity followed by moderate intensity (44% of time) and 3% at high intensity. Finally, results of subject 2 of this study differ as much from subject 1 as from the rest of the studies mentioned above because he was working at high intensity during 42.27% of the time. The remaining time was divided into low and moderate intensities (27.89% and 29.84%, respectively). This may be due to numerous factors such as recovery capacity in a relay test, age difference or basic aerobic capacity. The difference with other studies may be justified in that the race of the present study was conducted in two-minute series with two minutes rest while the rest of the studies were continuous races or relays of longer time.

Conclusions

The main aim of this study was to analyze ultra-endurance race where the mixed tandem 100 km indoor rowing World Record was broken. The strategy used by the pair of rowers was to alternate in two-minute series resting during the two minutes that the partner was rowing. Heart rate responses in this strategy showed that Z4 (81-90% HR_{max}) and Z5 (91-95% HR_{max}) were the most frequented heart rate zones. Most of the race time was spent between moderate and high intensity and the average concentrations of lactate were at ≈ 4 mmol/l.

This type of strategy used successfully in the World Record requires being able to reduce the attenuation of heart rate during repeated efforts with limited periods of recovery. Subjects with a high recovery capacity will reduce energy expenditure. In addition, the total time of the record and the large number of relays make aerobic capacity a very important characteristic. All this information can be useful for coaches and trainers to design training plans aimed at athletes who will perform ultra-endurance race in both rowing and other sports with similar strategies.

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