THE EFFECTS OF ROWING ERGOMETER DESIGN ON METABOLIC PARAMTERS DURING AN INCREMENTAL MAXIMAL TEST

Jere Gulin[1], Vlatko Vučetić[1], Stipo Dajaković[1], Goran Sporiš[1], Marino Krespi[2], Cain C.T. Clark[3]

[1]Faculty of Kinesiology, University of Zagreb, Croatia
[2]Faculty of Kinesiology, University of Split, Croatia
[3]Faculty Research Centre for Sport, Exercise, and Life Sciences, Coventry University, UK

Original scientific paper

Abstract

It has been reported that ergometer design can elicit biomechanical alterations in terms of single stroke power, stroke frequency and stroke length, in rowing. However, detailed examination of the metabolic and physiological milieu in response to ergometer design changes is warranted. Thus, the purpose of the present study was to compare the effect of two different rowing ergometer setups during an incremental maximal test on metabolic parameters. The sample consisted of 12 national and international level male rowers. Two different versions of the Concept 2 model E ergometer were used, in a static setup without slides and in a dynamic setup with the slides. The following metabolic parameters were analyzed: power output, oxygen uptake, heart rate peak and at anaerobic threshold, minute ventilation, breathing frequency, and respiratory volume. No significant differences were found in any of the monitored parameters. This suggests that ergometer design does not affect metabolic parameters during an incremental test, highlighting that coaches and practitioners can likely employ any reasonable ergometer set-up, without hindering the performer.

Key words: *VO_{2max}, aerobic power, anaerobic threshold*

Introduction

Indoor rowing accounts for a great number of training hours in senior-level rowing, is routinely used for testing and crew selections (de Campos Mello, de Moraes Bertuzzi, Grangeiro, & Franchini, 2009; Secher & Volianitis, 2007), and may be useful for the prediction of competition rankings (Mikulić, Smoljanović, Bojanić, Hannafin, & Matković, 2009). Stationary ergometers are regarded as a preferable option for indoor training, however, several different manufacturers and models are available on the market, but can be broadly dichotomized as static or dynamic rowing ergometers (Thornton et al., 2017).

The Concept II model E rowing ergometers are air-braked and have the flywheel connected by chain to the handle. As comprehensively described in paper by Greene and colleagues, the main movement on a rowing ergometer is performed in the anterior-posterior direction while seated on sliding seat (Greene, Sinclair, Dickson, Colloud, & Smith, 2013). In a stationary set-up, an ergometer is placed directly on floor and remains stationary during strokes, with only the rower's center of mass moving anteriorly and posteriorly. When a rowing ergometer is mounted on slides, thus permitting the ergometer to move back and forth during a rowing stroke, it is considered as dynamic ergometer (Greene, Sinclair, Dickson, Colloud, & Smith, 2013). Slides generally consist of a metal frame with tracks to mount rowing ergometer on, whilst the tracks are wheeled and are centered to the base by elastic cordage.

Competitive rowing, a sport which is highly dependable on the level of energetic capacities (Hagerman, 1984), requires routine, sport-specific, physiological assessment in order to gain insight into those capacities. A common approach for determining the level of energetic capacity is by using progressive incremental tests on rowing ergometers (Mäestu, Jürimäe, & Jürimäe, 2005; Mikulic & Bralic, 2018). Due to its specific demands, on-water rowing is not easily transferrable to indoor conditions; although a common way of bridging that gap is the use of dynamic rowing ergometers, which have recently been shown to represent a better predictor, and the physiological demands, of on-water rowing, as compared to static ergometers (De Campos Mello, Bertuzzi, Franchini, & Candau, 2014).

According to literature, rowing on dynamic ergometers, or using "slides", can reduce the risk of injury (Bernstein, 2002; Thornton et al., 2017), but it is not possible to differentiate power delivery and coordination patterns based on ergometer design

(Greene et al., 2013). Moreover, biomechanical and physiological parameters are reportedly discordant in rowing on stationary and dynamic ergometers (Benson, Abendroth, King, & Swensen, 2011; Holsgaard-Larsen & Jensen, 2010; Vinther et al., 2012). However, currently, there is a dearth of sufficient data regarding the metabolic and physiological milieu in response to ergometer design changes.

The main goal of this study was to determine the utility dynamic rowing ergometer be used in diagnostics procedures for estimation of aerobic capacity as well as the anaerobic threshold for determining training zones. Based on previous research (Benson et al., 2011; Holsgaard-Larsen & Jensen, 2010; Kerhervé et al., 2018) it is expected that there will not be significant differences in monitored parameters during tests on the stationary ergometer and dynamic ergometer and that there are no restrictions for using dynamic ergometer in diagnostics procedures.

Methods

Sample

The sample consisted of 12 healthy male rowers of national and international level (age = 20.0 ± 3.1 years; body weight = 82.9 ± 8.5 kg; body height = 188.5 ± 7.3 cm) with at least 4 years of competition experience. All participants had previous experience with rowing on both types of ergometers and the protocol used. All participants voluntarily participated in this study and signed written informed consent. In juvenile participants (under 18), parents/guardians informed consent was alos provided. The study was conducted in accordance with the Helsinki declaration.

Study design

All participants underwent one progressive incremental test on the stationary ergometer (SE) and one progressive incremental test on the dynamic ergometer (DE), performed in a random order, over a period of no less than 48 hours and no more than 72 hours. Testing procedure (protocol) was identical on both occasions. It consisted of one-minute rest, followed by 3 minutes of “warm-up” at 150 W, followed by a ramped increase of 25 W every 60 seconds until participants could not volitionally maintain appropriate load for 5 consecutive strokes. Stroke rate was not regulated, and self-selected by the participants. Drag factor was required to be the same for both tests. Both tests were performed on the same rowing ergometer, the Concept II, model E (Morrisville, Vermont, USA). Breath by breath oxygen uptake was measured using the Cosmed metabolic cart, software package Quark PFT suite 9.1b (Rome, Italy). Variables analyzed were obtained both at the maximal level and at the anaerobic threshold, including absolute and relative VO_2, heart rate and power output. Maximal values of minute ventilation, breathing frequency, and respiratory volume were also analyzed. The modified V-slope method (Schneider, Phillips, & Stoffolano, 1993) was used to determine the anaerobic threshold.

Statistical analysis

All data were analyzed using the software package Statistica 12.0 (Palo Alto, CA, USA). Normality of distribution was assessed, and subsequently confirmed, with the Shapiro-Wilk test. Paired sample t-test was used to assess differences between the data from two different rowing modalities. Data are presented as mean ± standard deviation. Level of statistical significance was set to 0.05.

Results

No significant differences were found between the stationary and fixed modality of rowing in all monitored metabolic parameters (Table 1). No significant difference was found for VO_2, HR and power output at maximal intensity. Breathing parameters were also similar in both protocols, with 1% lower maximal minute ventilation (Vu_{ma}) on a dynamic ergometer (DE), and slightly higher maximal breathing frequency (Bf_{max}) on DE, which resulted in lower maximal respiratory volume (Vt_{max}) on DE.

Table 1. Maximal values of aerobic power, oxygen uptake, and ventilatory parameters

Absolute oxygen uptake (lO_2/min), relative oxygen uptake (mlO_2/kg/min), heart rate (bpm), power output (W), minute ventilation (l/min), respiratory volume (l), breathing frequency (b/min)

Variable	SE	DE	p
VO_{2max} (lO_2/min)	5.727 ± 0.842	5.748 ± 0.765	0.846
RVO_{2max} (mlO_2/kg/min)	69.103 ± 7.175	69.483 ± 6.385	0.758
HR_{max} (bpm)	193.250 ± 7.852	193.168 ± 8.674	0.926
P_{max} (W)	422.917 ± 50.518	422.917 ± 40.533	1.000
VE_{max} (l/min)	181.350 ± 26.932	179.875 ± 25.385	0.636
Vt_{max} (l)	3.158 ± 0.587	3.143 ± 0.787	0.907
Bf_{max} (b/min)	67.058 ± 3.696	69.850 ± 5.283	0.136

Analysis of metabolic parameters achieved at anaerobic threshold showed that there were no significant differences between the two modalities of rowing (Table 2).

Table 2. Values of aerobic power and oxygen uptake at anaerobic threshold

Absolute oxygen uptake (lO_2/min), relative oxygen uptake (mlO_2/kg/min), heart rate (bpm), power output (W)

Variable	SE	DE	p
VO_{2anp} (lO_2/min)	5.226 ± 0.639	5.133 ± 0.691	0.413
RVO_{2anp} (mlO_2/kg/min)	63.216 ± 6.407	61.960 ± 5.276	0.357
HR_{anp} (bpm)	184.667 ± 8.414	185.333 ± 8.630	0.643
P_{anp} (W)	345.833 ± 36.670	345.833 ± 36.670	1.000

Discussion

The findings of this study suggest that there are no differences in metabolic parameters obtained during maximal incremental tests on both stationary and dynamic ergometers (DE). In addition, it is evident that when calculating training zones i.e. maximal vs. anaerobic threshold, the design of the ergometer, or ergometer setup, does not elicit any significant effect. Although some studies have reported that rowing on DE induces tangible changes in performance, such as reduced individual power per stroke with increased stroke frequency (Vinther et al., 2012), as compared to rowing on SE, the present study suggests that there is no impact on the recorded maximal aerobic capacity. These findings are in accordance with some previous research (Benson et al., 2011; Holsgaard-Larsen & Jensen, 2010); indeed virtually identical results for VO_{2max} and VO_{2ant} on both SE and DE were observed, suggesting that the design of the rowing ergometer does not affect the aerobic capacity of competitive rowers. Furthermore, training intensity zones that will be estimated through values at the anaerobic threshold will be the same, regardless of the ergometer design. Interestingly, there was marked differences in individual responses to varying ergometer design, thus, we present the individual responses in terms of peak oxygen uptake, as well oxygen uptake at the anaerobic threshold in figures 1. and 2. Clearly, although overall mean differences in insignificant, coaches and rowers should consider idiosyncratic preference and equipment availability when conducting maximal exercise testing.

Figure 1. Individual response for the maximal relative oxygen uptake (mlO_2/kg/min)

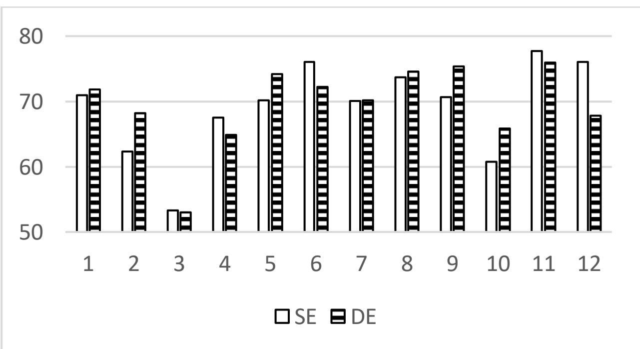
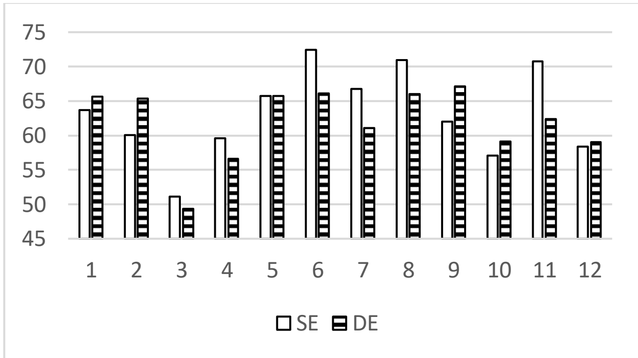


Figure 2. Individual response for the relative oxygen uptake(mlO_2/kg/min) at anaerobic threshold



Across both ergometer designs peak aerobic power output and power output at anaerobic threshold were concordant. These results are in agreement with previous studies (Holsgaard-Larsen & Jensen, 2010; Kerhervé et al., 2018) and confirm the hypothesis of this study. Although peak force and peak power per stroke were previously reported to be greater on SE (Bernstein, 2002; Colloud, Bahuaud, Doriot, Champely, & Chèze, 2006), it likely attributable to the relatively lower force applied per each stroke and accompanying greater stroke frequency, which results in similar overall power outputs to that of DE. One of the limitations of this study is that we did not monitor the stroke rate, and therefore no conclusions can be drawn. Considering breath-by-breath parameters (VE_{max}, Bf_{max}, Vt_{max}), no significant changes were found; this suggests that biomechanical changes that some studies have reported do not necessarily elicit changes in oxygen uptake, and that rowing on different ergometer design does not require adaptations in terms of breathing technique.

Limitations

A limitation of present study is relatively small sample size; however, the sample consisted of national and international level rowers, where recruitment of such participants can be difficult. In addition, the sample size recruited in the present study is comparable to numerous previous investigations of similar cohorts (De Campos Mello et al., 2014; Greene et al., 2013; Holsgaard-Larsen & Jensen, 2010; Kerhervé et al., 2018). Notwithstanding, however, larger sample sizes are needed to ensure ecological validity, and therein represents a viable avenue for further work.

Conclusion

The findings from this study show that the design of rowing ergometer does not affect oxygen uptake or metabolic parameters during the performance of a maximal incremental ramp protocol. Ramp protocols are often used to determine aerobic power and aerobic capacity, as well as to calculate training zones for further development and training; it is evident from this study that both stationary and dynamic rowing ergometer designs can be used, without providing spurious results.

References

Benson, A., Abendroth, J., King, D., & Swensen, T. (2011). Comparison of rowing on a concept 2 stationary and dynamic ergometer. *Journal of Sports Science and Medicine*, *10*(2), 267–273.

Bernstein, I. A. (2002). An ergonomic comparison of rowing machine designs: possible implications for safety. *British Journal of Sports Medicine*, *36*(2), 108–112. https://doi.org/10.1136/bjsm.36.2.108

Colloud, F., Bahuaud, P., Doriot, N., Champely, S., & Chèze, L. (2006). Fixed versus free-floating stretcher mechanism in rowing ergometers: mechanical aspects. *Journal of Sports Sciences*, *24*(5), 479–493. https://doi.org/10.1080/02640410500189256

De Campos Mello, F., Bertuzzi, R., Franchini, E., & Candau, R. (2014). Rowing ergometer with the slide is more specific to rowers' physiological evaluation. *Research in Sports Medicine*, *22*(2), 136–146. https://doi.org/10.1080/15438627.2014.881820

de Campos Mello, F., de Moraes Bertuzzi, R. C., Grangeiro, P. M., & Franchini, E. (2009). Energy systems contributions in 2,000 m race simulation: A comparison among rowing ergometers and water. *European Journal of Applied Physiology*, *107*(5), 615–619. https://doi.org/10.1007/s00421-009-1172-9

Greene, A. J., Sinclair, P. J., Dickson, M. H., Colloud, F., & Smith, R. M. (2013). The effect of ergometer design on rowing stroke mechanics. *Scandinavian Journal of Medicine & Science in Sports*, *23*(4), 468–477. https://doi.org/10.1111/j.1600-0838.2011.01404.x

Hagerman, F. C. (1984). Applied Physiology of Rowing. *Sports Medicine: An International Journal of Applied Medicine and Science in Sport and Exercise*, *1*(4), 303–326. https://doi.org/10.2165/00007256-198401040-00005

Holsgaard-Larsen, A., & Jensen, K. (2010). Ergometer rowing with and without slides. *International Journal of Sports Medicine*, *31*(12), 870–874. https://doi.org/10.1055/s-0030-1265148

Kerhervé, H., Chatel, B., Reboah, S., Rossi, J., Samozino, P., & Messonnier, L. (2018). Comparison of Prolonged Rowing on Fixed and Free-floating Ergometers in Competitive Rowers. *International Journal of Sports Medicine*, *39*(11), 840–845. https://doi.org/10.1055/a-0637-9613

Mäestu, J., Jürimäe, J., & Jürimäe, T. (2005). Monitoring of performance and training in rowing. *Sports Medicine*, *35*(7), 597–617. https://doi.org/10.2165/00007256-200535070-00005

Mikulic, P., & Bralic, N. (2018). Elite status maintained: a 12-year physiological and performance follow-up of two Olympic champion rowers. *Journal of Sports Sciences*, *36*(6), 660–665. https://doi.org/10.1080/02640414.2017.1329548

Mikulić, P., Smoljanović, T., Bojanić, I., Hannafin, J. A., & Matković, B. R. (2009). Relationship between 2000-m rowing ergometer performance times and World Rowing Championships rankings in elite-standard rowers. *Journal of Sports Sciences*, *27*(9), 907–913. https://doi.org/10.1080/02640410902911950

Schneider, D. A., Phillips, S. E., & Stoffolano, S. (1993). The simplified V-slope method of detecting the gas exchange threshold. *Medicine and Science in Sports and Exercise*, *25*(10), 1180–1184. https://doi.org/10.1249/00005768-199310000-00015

Secher, N. H., & Volianitis, S. (2007). *Rowing*. (N. H. Secher & S. Volianitis, Eds.). Oxford, UK: Blackwell Publishing Ltd. https://doi.org/10.1002/9781444312614

Thornton, J. S., Vinther, A., Wilson, F., Lebrun, C. M., Wilkinson, M., Di Ciacca, S. R., … Smoljanovic, T. (2017). Rowing Injuries: An Updated Review. *Sports Medicine*, *47*(4), 641–661. https://doi.org/10.1007/s40279-016-0613-y

Vinther, A., Alkjaer, T., Kanstrup, I.-L., Zerahn, B., Ekdahl, C., Jensen, K., … Aagaard, P. (2012). Slide-based ergometer rowing: Effects on force production and neuromuscular activity. *Scandinavian Journal of Medicine & Science in Sports*, *23*(5), 635–644. https://doi.org/10.1111/j.1600-0838.2011.01441.x

---

Corresponding information:

Received:10.02.2020.
Accepted: 23.05.2020.

Correspondence to: Jere Gulin
University: University of Zagreb
Faculty: Faculty of Kinesiology
Phone: +385955239817
E-mail: jere.gulin@kif.hr