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Research article

Sex-Related Differences in Self-Paced All Out High-Intensity Intermittent Cycling: Mechanical and Physiological Responses

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Abstract

The purpose of this study was to compare sex-related responses to a self-paced all out high-intensity intermittent exercise (HIIE). 9 women and 10 men were submitted to a maximal incremental test (to determine maximum aerobic power - MAP and VO_{2peak}), and an HIIE cycling (60x8s:12s, effort:pause). During the protocol the mean value of $\dot{V}O_2$ and heart rate for the entire exercise (VO_{2total} and HR_{total}) as well as the values only in the effort or pause ($\dot{V}O_{2effort}$, VO_{2pause} and HR_{effort} and HR_{pause}) relative to VO_{2peak} were measured. Anaerobic power reserve (APR), blood lactate [La] and the respiratory exchange ratio (RER) were also measured. These variables were compared between men and women using the unpaired t test. Men used greater APR (109 ± 12%MAP vs 92 ± 6%MAP) with similar $\dot{V}O_{2total}$ (74 ± 7 vs 78 ± 8% VO_{2peak}), however, when effort and pause were analysed separately, $\dot{V}O_{2effort}$ (80 ± 9 vs 80 ± 5%VO_{2peak}) was similar between sexes, while $\dot{V}O_{2pause}$ was lower in men (69 ± 6% vs 77 ± 11% VO_{2peak}, respectively). Women presented lower power decrement (30 ± 11 vs 11 ± 3%), RER (1.04 ± 0.03 vs 1.00 ± 0.02) and $[La]_{peak}$ (8.6 ± 0.9 vs 5.9 ± 2.3 $mmol.L^{-1}$). Thus, we can conclude that men self-paced HIIE at higher APR but with the same cardiovascular/aerobic solicitation as women.

Key words: Oxygen uptake, sexual dimorphism; anaerobic power reserve.

Introduction

Typically, moderate intensity continuous exercise has been recommended for improving aerobic fitness (Garber et al., 2011), however high-intensity intermittent exercise (HIIE) has gained popularity due to its benefits in improving aerobic fitness (Helgerud et al., 2007), while being executed in a short period of time (Gillen and Gibala, 2014). Although HIIE has been studied and is currently recommended (Garber et al., 2011) there are still some questions about its prescription due to the characterization of some acute physiological and mechanical responses which are not fully elucidated as the total work done, intensity relative to maximum indexes (percent of maximum power output and maximal oxygen uptake). This is a result of the large number of variables that can be manipulated during HIIE (Buchheit and Laursen, 2013). With respect to intensity, a practical mode for prescribing HIIE is through all out efforts, as this type of exercise does not require a prior test to identify exercise intensity. In this kind of exercise the maximal intensity is employed and the participant can self-regulate the intensity of the efforts according to their knowledge of the total volume of the session (Billaut et al., 2011).

Another important aspect that needs to be considered in the prescription of all out HIIE is that the physiological and mechanical responses to HIIE are affected by sexual dimorphism (Billaut et al., 2012). Studies investigating differences between men and women in all out efforts utilized protocols composed of a single effort (Esbjörnsson-Liljedahl and Jansson, 1999; Leicht et al., 2011; Lovell et al., 2011; Perez-Gomez, 2008), or brief repeated efforts (Billaut et al., 2003; 2009; 2012; Laurent et al., 2010; Townsend et al., 2014). In general, men achieved higher peak and mean power, while women demonstrated lower performance decrements (Billaut et al., 2009; Leicht et al., 2011; Perez-Gomez et al., 2008), even when performance was relativized by body mass (Perez-Gomez et al., 2008). Physiological mechanisms responsible for sex-related differences may involve differences in energy metabolism (Hunter, 2014) being that greater power performed by men can be explained by their superior anaerobic potential (Esbjörnsson-Liljedahl and Jansson, 1999) and a greater proportion of carbohydrate utilization (Carter et al., 2001).

However, little is known concerning more prolonged high-intensity intermittent all-out exercise (those featuring an HIIE session), predominantly protocols that are effective for decreasing fat mass and increasing long-term aerobic fitness. Thus, knowledge of acute responses to this type of exercise could help to create inferences about long-term adaptations (Trapp et al., 2008).

Performance relative to maximal aerobic power (MAP), oxygen uptake (VO_2) and heart rate (HR) relative to its maximum values (VO2peak and HRmax, respectively) are indices relevant for training prescription, and aerobic and anaerobic adaptation to training depends on these parameters (Buccheit and Laursen, 2013). However, these responses during self-paced all out HIIE are not understood, especially with regard to sex differences.

Thus, the objective of the present study was to compare the performance (total work and power decrement), utilization of anaerobic reserve, blood lactate (peak

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and delta), respiratory exchange rate, VO_2 and HR relative to its maximum index in response to a high-intensity intermittent all-out exercise protocol between men and women. Thus, the main hypotheses of the present study were that the men would perform HIIE in higher intensities in terms of power than women, with same cardiovascular responses (oxygen uptake and heart rate) indicating a greater utilization of anaerobic pathways.

Methods

Experimental design

Participants completed three experimental sessions separated by at least 72 hours. During the first session, anthropometric measurements and VO_2peak test on a cycle ergometer were taken. In the second session, the participants were submitted to a familiarization of high-intensity intermittent all out exercise protocol (60 sprints of 8s effort and 12s pause), and in the third session they performed the exercise *per se*. This protocol was chosen because it was shown to improve aerobic fitness and reduce the fat mass (Heydari et al., 2012; Martins et al., 2015; Trapp et al., 2008).

Participants

Ten men and nine women, physically active, participated in this study. Participants were included if they did not report any health problems and/or neuromuscular disorders that could affect their ability to complete the study protocol. Furthermore, all were free of any drug or ingestion of nutritional supplements during the period of the study. Participants took part voluntarily in the study after being informed about the procedures, risks, and benefits and signed an informed consent form. This study was approved by the local ethics committee. The women were tested in the follicular phase (1 - 10 days after the onset of menstruation) of the menstrual cycle.

Anthropometric measurements

Height was measured using a stadiometer with a metric scale affixed to the floor, and body mass were measured using an electronic scale (precision 0.01kg). Body fat percentage was estimated via skinfold, circumferences and bone diameter measurement (Drinkwater and Ross, 1980). Skinfold thickness measurements were carried out using a Harpender plicometer (John Bull British Indicators, England), three times at each point in a rotation system (the median value was used), as described by Drinkwater and Ross (1980).

Incremental test

The participants performed an incremental test to volitional exhaustion on an electronically braked cycle ergometer (Lode, Netherlands). The initial load was set at 30W and it was increased by $25W \cdot min^{-1}$ for men and 15 $W.min^{-1}$ for women. Cadence was set at 70rpm, and subjects were instructed to perform the test until they could no longer continue. The test was finished when subjects could not maintain the load for 5s in the fixed cadence. Strong verbal encouragement was given during the test. The VO_2 was measured (MetaMax®3B, *Cortex*, Germany) throughout the test and the average of the last 30s was defined as VO_2peak. The maximal load reached in the test was defined as the maximal aerobic power (MAP). When the subject was not able to finish the 1-minute stage, the power was expressed according to the permanence time in the last stage, determined as the following: maximal aerobic power = power of last stage completed + [(time, in seconds, remaining in the last stage multiplied by 25W or 15W)/60s]. The respiratory compensation point (RCP) was determined by point of a nonlinear rise in the ventilation (VE) related to carbon dioxide volume (VCO_2) (Meyer et al., 2005).

High-intensity intermittent all out exercise

Participants performed a warm-up at 50% MAP for 5-min, and after a 2-min rest interval they started the all out exercise. Participants cycled (electronically braked cycle ergometer) as fast as possible 60 times for 8 s interspersed by 12 s of passive recovery (totalling a 20-min session). The load used was 4% and 2.5% of the body mass for men and women, respectively. In each effort they had a rolling to start and 55 W as used during each recovery period. Moreover, they had a standardized countdown started at the each effort.

The work done in each effort was registered and the sum of all the efforts was considered the total work done (kJ). Mean power and peak power in each effort was registered. Power decrement (%) was calculated using the following equation: (sum of efforts divided by best effort multiplied by number of efforts minus 1) *100 (Girard et al., 2011).

To ensure that all out exercise was reliable, it was registered the performance in both exercise session (familiarization and experimental session). There were no differences for total work performed between sessions for women ($p = 0.465$; intraclass correlation coefficient = 0.969 and limits of agreement between - 9 to 7 kJ), or men ($p = 0.572$; intraclass correlation 0.952 and limits of agreement between - 11 to 12 kJ) (Bland and Altman, 1986), but only data from experimental session was used to comparison between men and women.

Utilization of anaerobic power reserve in each effort was also calculated being: peak power minus MAP of each effort (Mendez-Villanueva et al., 2008), and it was calculated also for mean power of each effort (mean power minus MAP).

VO_2 was measured during the whole exercise and data registered breath by breath. The values breath by breath were interpolated each second (Origin 6.0, Microcal, Massachusetts, USA), and was analyzed relative to VO_2peak: mean of total exercise (VO_{2total} % VO_2peak), only effort ($VO_{2effort}$ %VO_2peak), and only pause (VO_{2pause} % VO_2peak). The heart rate was also recorded during all exercise and was analyzed relative to HRmax: mean of total exercise (HR_{total} %HRmax), only effort (HR_{effort} %HRmax), and only pause (HR_{pause} %HRmax). Additionally, the mean of respiratory exchange ratio (RER) in effort (RER_{effort}) and pause (RER_{pause}) was used.

Blood samples from the ear lobe were taken to determine the lactate concentration (Yellow Spring 1500 Sport, Yellow Springs, United States) before and 1, 3 and

5-min after the all out exercise, and was calculated the lactate peak (maximum value after the exercise) ([La]peak) and the delta of lactate (peak lactate concentration after the exercise minus the lactate concentration at rest) ([La]delta).

Statistical analysis

The data were analyzed using the Statistical Package for Social Sciences 18.0 (SPSS Inc., Chicago, IL, USA) and presented as means and standard deviations. The normality of data was checked by Shapiro-Wilk. All dependent variables were compared through unpaired Student t tests. Statistical significance was set at P < 0.05. Effect size to multiple paired comparisons were calculated by Cohen'*d* and were classified according Hopkins , 2016: < 0.2 – trivial; > 0.2 and < 0.6 – small; > 0.6 and < 1.2 – moderate; > 1.2 and < 2.0 – large; > 2.00 and < 4.0 – very large; < 4.0 – nearly perfect.

Results

For subjects characteristics (Table 1) men present higher body mass (t = 4.7; p < 0.001; *d* = 2.00), height (t = 4.5; p < 0.001; *d* = 1.75), MAP (t = 5.5; p < 0.001; *d* = 2.57), absolute (t = 5.4; p < 0.001; *d* = 2.53) and relative VO_2peak (t = 3.3; p = 0.004, *d* = 1.53), lean body mass (t = 2.79; p = 0.009; d = 1.29), power at RCP (t = 5.96; p < 0.001 d = 2.80) and VO_2 at RCP (t = 26.5; p < 0.001; d = 3.47), and lower body fat (t = 4.4; p = 0.001; *d* = 1.70).

Men performed higher total absolute work than women (t = 6.8; p < 0,001; *d* = 13.16), as well as relative total work (t = 6.1; p < 0.001; *d* = 3.79), and had higher power decrement (t = 5.0; p < 0.001, *d* = 2.36). There were no differences between sexes for [La] delta, but men presented higher values compared to women for [La] peak (t = 1.74; p = 0.028 *d* = 0.83) and RER_{pause} (t = 1.74; p = 0.041; *d* = 0.84) (Table 2).

Utilization of anaerobic power reserve was higher in men concerning mean power (t_{17} = 2.10; p < 0.001; *d* = 1.80; 109 ± 12% of MAP vs 92 ± 6% of MAP) and peak power (t_{17} = 7.46 d = 3.17; p < 0.001; 128 ± 9 vs 101 ± 8%) (Figure 1).

There were no differences in sexes concerning % VO_{2total} (Panel A in Figure 2) (74 ± 7% for men and 78 ± 8% for women) and $VO_{2effort}$ (Panel C in Figure 2) (80 ± 6 % for men and 80 ± 8 % for women) relative to VO_2peak, but lower values in VO_{2pause} (t = 1.99; p = 0.031; *d* = 1.55, large) was observed in men (69 ± 4 % of VO_2peak) compared to women (76 ± 5 % of VO_2peak) (Panel E in Figure 2). Moreover, higher difference in $\dot{V}O_2$ ($VO_{2effort}$ minus VO_{2pause} relative to VO_2peak) was observed (t_{17} = 1.73; p = 0.040; *d* = 0.85) in men (11%) compared to women (4%).

There were no differences in sexes concerning $\%HR_{total}$ (89 ± 5 for men and; 87 ± 7 for women), $\%HR_{effort}$ (89 ± 6 for men; 89 ± 6 for women) $\%HR_{pause}$ (89 ± 5 for men; 89 ± 5 for women).

Discussion

The main finding of the present study was that men achieved higher total work, utilization of anaerobic

Table 1. Subjects characteristics. Data are means (±SD).

	Men (n = 10)	Women (n = 9)
Age (years)	27 (3)	27 (3)
Body mass (kg)	78.5 (7.8) *	61.8 (7.6)
Heigth (m)	1.78 (.08) *	1.64 (.08)
Body fat (%)	14.5 (2.7) *	20.9 (3.7)
Body lean mass (%)	44.0 (3.6) *	40.3 (2.5)
Maximum aerobic power (W)	288 (51) *	187 (22)
Maximum heart rate (bpm)	184 (8)	183 (8)
VO_2peak absolute ($L \cdot min^{-1}$)	3.4 (.6) *	2.2 (.3)
VO_2peak relative ($ml \cdot kg \cdot min^{-1}$)	43.3 (4.7) *	36.2 (4.6)
Respiratory exchange ratio	1.26 (.07)	1.26 (.05)
Rating of Perceived Exertion	19.7 (.7)	19.7 (.5)
Power at RCP (W)	238 (41) *	150 (17)
Power at RCP (%MAP)	83 (7)	81 (8)
HR at RCP (bpm)	162 (11)	163 (14)
HR at RCP (%HRmax)	89 (6)	88 (4)
VO_2 at RCP ($l \cdot min^{-1}$)	2.8 (.4) *	1.7 (.2)
VO_2 at RCP (%VO_2peak)	82 (8)	77 (11)

* = different from women (p < 0.05). VO_2: oxygen uptake; RCP: respiratory compensation point; HR: heart rate; MAP: maximum aerobic power.

Table 2. Work done, power decrement, lactate concentration and RER in all out exercise (60 times for 8s interspersed by 12s of passive recovery). Data are means (±SD).

	Men (n = 10)	Women (n = 9)
Work perfomed (kJ)	146 (26) *	82 (12)
Work performed ($kJ.kg^{-1}$)	1.9 (.2) *	1.3 (.1)
Power decrement (%)	30 (11) *	11 (3)
[La] delta	7.1 (.9)	5.9 (2.3)
[La] peak	8.6 (.9) *	7.1 (2.2)
RER_{effort}	1.02 (.06)	.99 (.03)
RER_{pause}	1.03 (.06) *	.99 (.03)

RER = ratio exchange respiratory; * = different from women (p < 0.05).

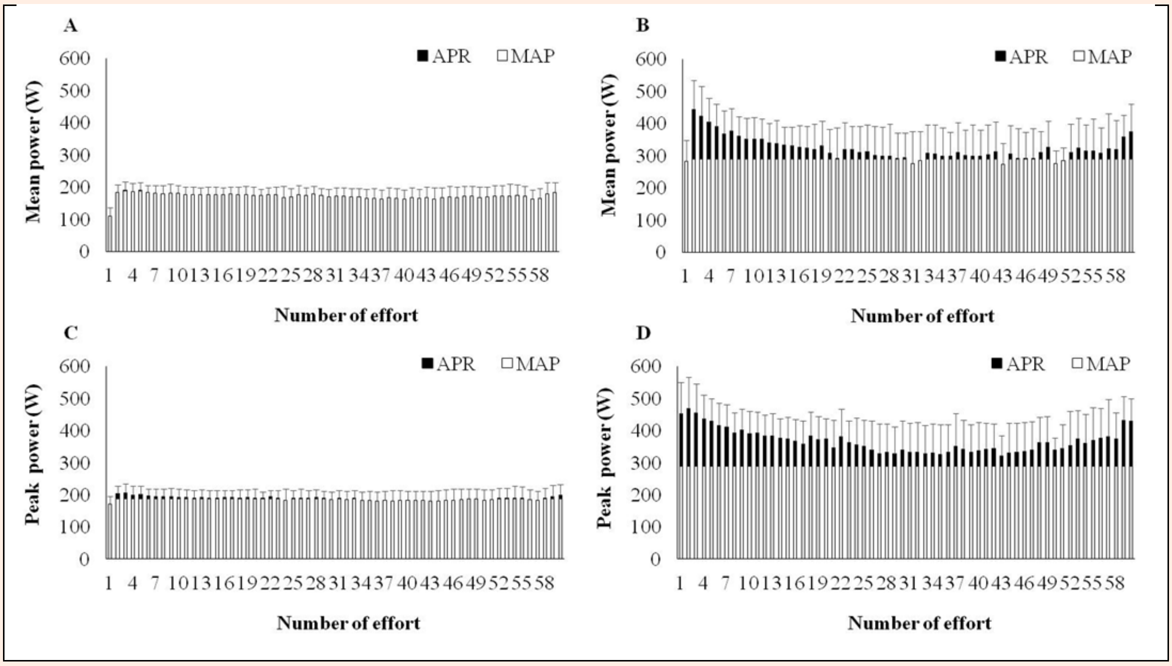

Figure 1. Utilization of anaerobic power reserve concerning mean power in women (Panel A) and men (Panel B) and peak power in women (Panel C) and men (Panel D) in all out exercise (60 times for 8s interspersed by 12s of passive recovery).

reserve (peak and mean power - above MAP), [La] peak and power decrement, concomitantly with lower values of VO_{2pause} ($\%VO_{2peak}$), compared to women during the all out exercise. No differences were observed between sexes for HR_{total}, HR_{effort} and HR_{pause} relative to HR_{max}, [La] delta, VO_{2total} or $VO_{2effort}$ relative to VO_{2peak}.

The higher intensity and power decrement generated by men in the entire exercise is not novel, since various studies have already reported this (Billaut et al., 2012), although the majority used a single effort or short repeated efforts (similar to the Wingate test). The novel finding is that the higher power output generated by men was sustained with the same relative VO_{2total}, but performed with higher utilization of the anaerobic reserve. In other words, in all out exercise men exhibit a different self-pacing to women, choosing an intensity above MAP, while women set the intensity under or at MAP (see Figure 1). Self-pacing was compared between sexes (Laurent et al., 2014) in a protocol composed of all-out running (4-min effort: 1, 2 or 4-min of recovery) and men chose a higher intensity relative to MAP compared to women, 83% vs 78% in the longest recovery interval.

Another result was that men exhibited lower VO_{2pause} relative to VO_{2peak} values during the recovery intervals than women, however with similar values in VO_{2total} and $VO_{2effort}$ relative to VO_{2peak}. Laurent et al. (2014) also measured the VO_2 in men and women in high-intensity intermittent exercise, however VO_2 was measured only in the final minute of the recovery periods and the VO_2 was greater in women compared to men (90.8 ± 3.8 vs 85.9 ± 4.2% VO_{2peak}) only in the longest recovery interval (4 minutes). The greatest reduction in VO_2 demonstrated by men in the recovery intervals occurred in the study of Laurent et al. (2014) and in the present study could be explained by the higher aerobic fitness of men, since higher aerobic fitness allows a fast reduction in oxygen uptake during the recovery intervals (Panissa et al., 2014).

Considering that the men performed higher mean power in the all out exercise with the same oxygen uptake and heart rate as the women, we can assume that in fact the difference in performance can be explained by greater anaerobic potential produced by the men. The greater reliance on the anaerobic pathways demonstrated by men could be sustained by the greater utilization of the anaerobic power reserve, since men used 27% of their anaerobic power reserve while women used only 2%. Within the literature it is not possible to explain why women did not use a higher fraction of their anaerobic reserve and more studies should be conducted to clarify this.

However, observing a study that analyzed the effects of sexual dimorphism in another kind of exercise (marathon), Deaner et al. (2015) showed that women maintained mean variation of pacing of 12 % and men 16%, even when this comparison was matched by experience or corrected by differences in the final race time. In this way, it seems that different self-pacing chosen by men and women is either an isolated characteristic or in conjunction with physiological and decision-making. In the case of decision-making, men tend to adopt a higher risk strategy based on their physical fitness (Deaner et al., 2015). Moreover, men seem to be more motivated to perform exercise than women (Deaner et al., 2015).

The only study that reported load (velocity) relative to maximum indices was Laurent et al. (22), however, in this study the duration of effort was too long (4 mins) making a direct comparison with the present study difficult. Moreover, it is important to highlight that the longer

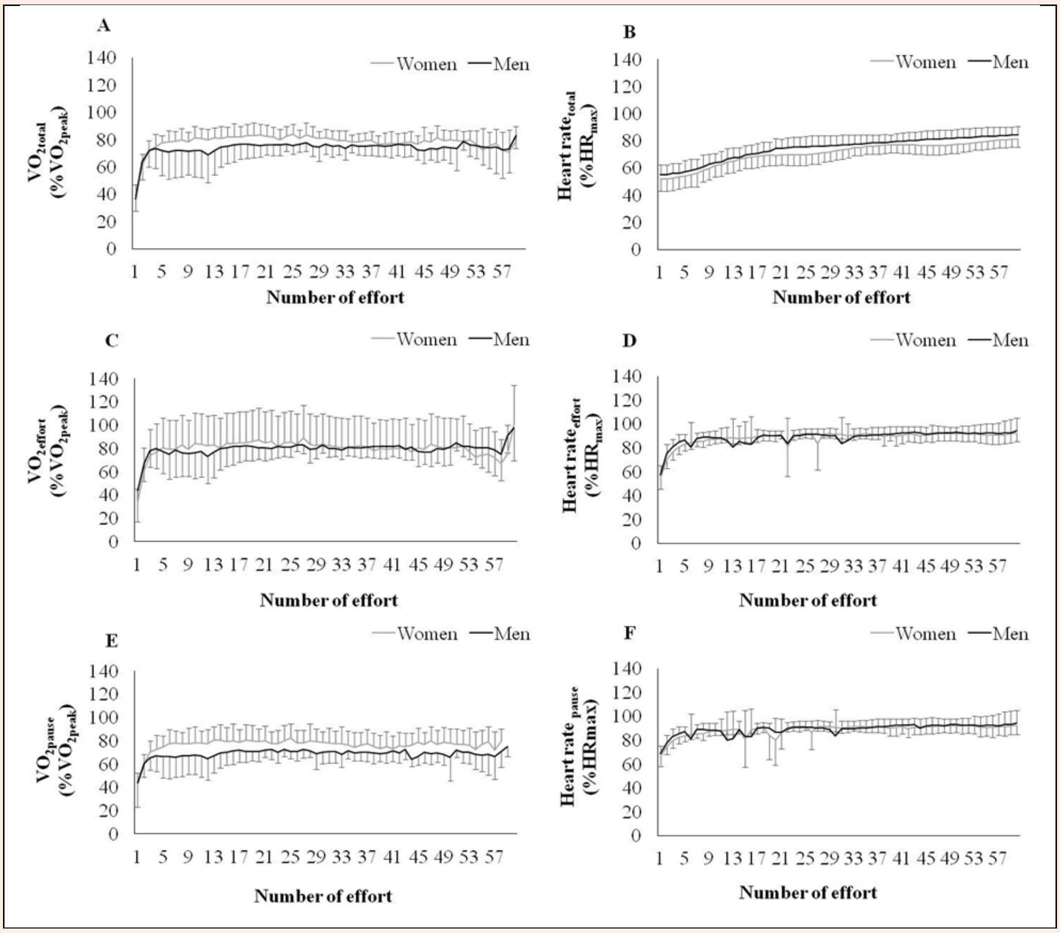

Figure 2. Oxygen uptake and heart rate relative to maximum values in all out exercise (60 times for 8s interspersed by 12s of passive recovery) for total (Panels A and B), effort (Panels C and D) and pause values (Panels E and F) in men and women. Data are men ± standard deviation; for VO_{2pause}, higher values in women compared to men ($p < 0.05$).

effort duration (4 minutes) did not allow participants to attain and maintain high loads (Tschakert et al., 2013, 2015).

In relation to the higher blood lactate and respiratory exchange ratio values, there is clear evidence that the respiratory exchange ratio values are higher in men than women considering exercises equalized by intensity, due to factors such as oestrogen which can lead to greater oxidation of fatty acid by women (Devries et al., 2016). However, in the present study we believe that this also occurred due to the greater utilization of the anaerobic power reserve and consequently higher glycolytic flux that has glucose as the major substrate (Spriet, 2014). The greater power output performed by men, mainly in the initial phase of the sprints, is related to greater reliance on the anaerobic pathways and the subsequent inhibition of contractile properties (Parolin et al., 1999; Tchakert et al., 2015) in later sprints, culminating in greater power decrement.

Concerning delta and peak lactate we detected just differences in lactate peak and probability it occurs due greater muscle mass presented by men. Already over respiratory exchange ratio values, there is clear evidence that the values are higher in men than women considering exercises equalized by intensity (Devries et al., 2016). In the present study we believe that this can be occurred due to the greater utilization of the anaerobic power reserve and consequently higher glycolytic flux, although we did measured the glycolytic flux it is just a speculation that has glucose as the major substrate (Spriet et al., 2014). The greater power output performed by men, mainly in the initial phase of the sprints, is related to greater reliance on the anaerobic pathways and the subsequent inhibition of contractile properties in later sprints, culminating in greater power decrement (Parolin et al., 1999; Tschakert et al., 2015).

The mean heart rate (~90% of HR_{max}) maintained during the all out exercise indicated that this kind of exercise had a high cardiovascular solicitation; although the mean of VO_2 was much lower (~80 % VO_2peak). The HR is a common and highly utilized exercise intensity marker. In steady state exercise the $HR/\dot{V}O_2$ ratio is well established to show a linear relation (Achten and Jeukendrup, 2003), but this is not occur in incremental tests (Hofmann et al. 1997; 2001; 2005). Moreover, in high-intensity intermittent exercise HR is not able to represent exercise intensity, given that HR usually does not follow the VO_2 during high-intensity intermittent exercise, especially when short-intervals (< 30 seconds) are used, since there is a delay in HR response compared with VO_2 (Tschakert et al. 2013; 2015).

Thus, it is important to conduct studies to verify the role of physiological and behavioural characteristics in self-paced all out exercises, using strategies to isolate these variables. For isolation of behavioural aspects (decision-making) blinded studies could be conducted (Billaut et al., 2011), mainly for women. For physiological aspects, studies using a fixed load in order to induce supramaximal values could be useful to compare variables such as the oxygen uptake, heart rate and blood lactate. Moreover, it is also possible to match men and women by aerobic fitness or by first sprint to observe these responses, as performed by Billaut and Bishop (2012), who observed differences between men and women in 20 x 5s:25s. However, when these authors carried out equalization by peak power generated in the first sprint with sub-groups, they observed that total work and power decrement were similar between men and women. Nevertheless, this study did not measure oxygen uptake and was performed with team sports athletes which permits this kind of equalization.

Conclusion

In a high intensity intermittent self-paced exercise the responses of men and women (physically active) are clearly different. Although oxygen uptake during exercise was equal between sexes, men chose higher loads, using more of their anaerobic power reserve and consequently presenting higher power decrement, respiratory exchange ratio and lactate peak.

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Key points

- Men self-paced high-intensity intermittent exercise at higher intensities than women.
- Men utilized greater anaerobic power reserve than women.
- Men and women had same cardiovascular solicitation.

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