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Title:

Is RPE a valuable tool for monitoring exercise intensity during steady-state conditions in elite endurance athletes?

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ABSTRACT

Purpose: Rating of perceived exertion (RPE) is a widely used tool to assess subjective perception of effort during exercise. We investigated between-subjects variation and effect of exercise mode and sex on Borgs RPE (6-20) in relation to heart rate (HR), oxygen uptake (VO_2) and capillary blood lactate concentrations ($[La^-]$). **Methods:** 160 elite endurance athletes performed a submaximal and maximal test protocol either during cycling (n=84, 37 women) or running (n=76, 32 women). The submaximal test consisted of 4-7 progressive 5-min steps within ~50-85% of VO_{2max}. For each step, steady-state HR, VO_2, and $[La^-]$ were assessed and RPE reported. An incremental protocol to exhaustion was used to determine VO_{2max} and HR_{peak} to provide relative (%) HR and VO_2 values at submaximal work rates. **Results:** A strong linear relationship was found between RPE and %HR, $\%VO_2$ and $[La^-]$ (r=0.74-0.84, all $P<0.05$). The between-subject coefficient of variation (SD/mean) for %HR and $\%VO_2$ decreased linearly with increased RPE, from ~10-15% at RPE 8 to ~5% at RPE 17. Compared to cycling, running induced a systematically higher %HR and $\%VO_2$ (~2 and 5%, respectively, $P<0.05$) with these differences being greater at lower intensities (RPE <13). At the same RPE, women showed a trivial, but significantly higher %HR and $\%VO_2$ than men (<1%, $P<0.05$). **Conclusions:** Among elite endurance athletes, exercise mode influenced RPE at a given %HR and $\%VO_2$, with greater differences at lower exercise intensities. Athletes should manage different tools to evaluate training based on intensity and duration of workouts.

Keywords: Blood lactate concentration, Exercise intensity, Exercise mode, Heart rate, Maximal oxygen uptake, Rating of perceived exertion

INTRODUCTION

Endurance training is tailored to the athlete's goals by manipulating exercise intensity, duration, and frequency to achieve the desired training load. While duration and frequency are straightforward to plan, execute and evaluate, intensity is inherently more complicated [1,2]. Several approaches to manage intensity are used by endurance athletes, categorized as internal objective-, internal subjective- or external markers. The latter is typically speed ($m \cdot s^{-1}$) and power output (W). Objective internal markers are first and foremost oxygen consumption (VO_2), heart rate (HR), and capillary blood lactate concentrations ($[La^-]$), while subjective internal markers are various forms of ratings of perceived exertion (RPE) [1,3].

RPE is widely used to assess effort and/or exertion during exercise, both in patients and athletes. It can be easily collected and analyzed, and is valuable in understanding the psychophysiological stress experienced during physical activity [4,5]. Borg's 6-20 scale [6] is the most commonly used RPE-scale and it has been validated against HR and $[La^-]$ in both sedentary individuals and athletes [7-9]. Moreover, it has been claimed that sex, physical activity status and exercise modality (e.g., running or cycling) do not influence these associations, implying that the RPE Borg 6-20 scale can be used interchangeably to assess and control training intensity [8,10,11]. However, little evidence exists of the associations between RPE and physiological markers in elite male and female endurance athletes. This is of importance since elite endurance athletes demonstrate higher fractional utilization of VO_{2max} than well-trained athletes [12], indicating that the relationship between the relative (%) HR and VO_2 values, as well as $[La^-]$ may differ between athletes of different performance levels.

Elite endurance athletes typically perform and monitor their training relative to an intensity scale, often divided into 3 or 5 arbitrary zones, as exemplified by the American College of Sports Medicine (ACSM) [13], guidelines from the Norwegian Olympic Federation [2] or summarized in reviews of the literature [1]. However, to be used appropriately in elite athletes, an evidence-based guideline between the most used "tools" is warranted. This is important for elite endurance athletes, as control of intensity may be critical for maximizing performance and minimizing risk of negative training outcomes [14]. However, the acute physiological responses to exercise differ among elite athletes and, as such, standardized scales have been criticized as they fail to account for these individual variations [2]. These variations between athletes have not been fully described. Forcing all athletes into a "one-size fits all" by using fixed intensity zones, may result in individual differences in physiological stimuli being neglected. Therefore, the typical between-subject variation and the limitations of different tools for assessing exercise intensity are important to consider.

The purpose of the present study was to compare Borg`s RPE 6-20 scale with %HR, $\%VO_2$ and $[La^-]$ from low to high steady-state exercise intensities in elite endurance athletes. Moreover, we aimed to investigate the between-subject variation, along with potential differences between exercise modes and sexes, and thereby provide an evidence-based framework for developing intensity scales for elite endurance athletes.

METHODS

Subjects

A cohort of 160 elite male and female endurance athletes participated in the study and their baseline characteristics are shown in Table 1. The athletes were member of national teams (junior or senior teams) in their sports. There were no significant differences in VO_{2max} between subjects in running and cycling for men or women, respectively. All subjects regularly conducted testing at the Norwegian Olympic training center and were therefore familiar with the protocols. This was a retrospective study based on pre-existing data collected in the period 2015-2020 at The Norwegian Olympic Training Centers (Oslo and Lillehammer, Norway), and informed written consent was obtained from all subjects.

<<Table 1 near here>>

Design

Each athlete conducted a submaximal and a maximal test, either running or cycling based on their sport-specific testing regime. Seventy-six athletes performed a running test (cross-country skiers, biathletes and orienteers) and 84 performed cycling (mountain bikers, road cyclists, speed skaters). In this data set, only one test per athletes was included, with this being the athlete´s most recent test. During these tests, RPE, HR, VO_2 and [La^-] was collected. RPE was reported directly after each 5-min step and was evaluated using a category ratio RPE scale (6–20) [6] provided in Table 2 and found comparable to the category-ratio 10 scale [15].

Methodology

The running test was performed at a 6° incline and initiated at 6.6, 7.5, 8.4 or 9.3 $km \cdot h^{-1}$, based on the level of athlete. The test progressed with increments of 0.9 $km \cdot h^{-1}$ for each 5-minute step until an RPE of >15 was reached. The number of stages ranged from 4 to 7. Cardiorespiratory variables were obtained from 2 to 4 min, and the average from 3 to 4 min was used for further analysis. Average HR from 4:30-5:00 was used. A 30-second passive break was conducted to obtain [La^-].

In the cycling, the initial workload was based on performance level and previous testing and was increased by 20/25 W (female/male) increments every 5 minutes without breaks. The number of stages ranged from 4 to 7. The test was terminated based upon the same criteria as the running test, and cardiorespiratory variables and HR were monitored in the same way as in the running test.

The submaximal test was followed by an incremental VO_{2max} test to volitional exhaustion after a 5-10-minute break of self-paced active recovery at low intensity. Participants were instructed to use hand signals to indicate whether they wished to further increase the workload during the final minutes of the test (thumb up = increase 1 $km \cdot h^{-1}$, half thumb = increase 0.5 $km \cdot h^{-1}$, flat hand = maintain current speed). Participants were instructed that if they chose to increase the workload, this should be maintained for a minimum of one new minute. The running test started at 9-11 $km \cdot h^{-1}$, based on the level of participants, and progressed with increases of 1 $km \cdot h^{-1}$ every minute until the test leader asked participants and hand signals were given. The highest continuous VO_2 during a 60-second period was defined as VO_{2max}. The highest HR during a 5-second period was defined as HR_{peak}. In cycling, the protocol was similar, where starting power output was 200-250W (based on the level of participants) and increased by 20/25W (female/male) every minute until exhaustion or cadence <60 revolutions of per minute.

Apparatus

Oxygen consumption was measured using an automatic ergospirometry system with a mixing chamber set-up (Oxycon Pro, Jaeger Instruments, Hoechberg, Germany), as evaluated by Foss, Hallen [16]. $[La^-]$ was measured using a Biosen C-Line GP+ lactate analyzer (Biosen C-line, EKF Diagnostic, Cardiff, UK) or in non-hemolyzed capillary fingertip blood (YSI 1500 Sport; Yellow Springs Instruments, Yellow Springs, OH). Based on a pilot study with 82 parallel samples (R^2 =0.99) analyzed with both YSI and Biosen, the YSI values were multiplied by 1.43 + 0.04. All $[La^-]$ values presented in the manuscript are Biosen compatible. The lactate analyzer and metabolic system were calibrated according to the relevant instruction manuals. HR was measured with a Polar heart rate RS400 or M400 monitor (Polar Electro OY, Kempele, Finland). Body mass were measured on a Seca stadiometer and a Seca Model 708 (Voegel & Halke, Hamburg, Germany) and body height reported.

Cycle tests were performed on a Lode Excalibur Sport ergometer (Lode B. V., Groningen, The Netherlands) calibrated according to the manufacturer's recommendations. Running tests were performed on Woodway (GmbH,Weilam Rhein, Germany) or Lode (Lode Katana sport, The Netherlands) treadmill.

Statistical Analysis

Normality of the data was assessed using the Shapiro–Wilks test of normality (a = 0.05). Data are shown as mean and SD. A 2-way ANOVA was run between RPE and exercise mode, and RPE and sex, respectively, to determine the main effect and their interaction. If a main effect of exercise mode or sex was found, a Holm-Sidak post hoc pairwise comparisons was applied. The magnitude of differences between running and cycling and between males and females was expressed as standardized mean differences (Cohen's d effect size; ES) with the formula $(M_2\text{-}M_1)/SD_{pooled}$. Correlation coefficients (Pearson product–moment correlation) were classified according to Hopkins, Marshall, Batterham, Hanin [17]. Statistical calculations were performed using Microsoft Office Excel 2013 (Microsoft, Redmond, USA) and SigmaPlot version 13.0 software (San Jose, CA, USA). A *P*-value ≤ 0.05 was considered statistically significant.

RESULTS

The association between RPE and %HR, $\%VO_2$ and $[La^-]$ for the total cohort are shown in Table 2. The between-subject coefficient of variation (SD/mean) for the respective variables as a function of RPE are shown in Figure 1. The between-subject coefficient of variation for %HR and $\%VO_2$ decreased linearly with increased RPE, from ~10-15% at RPE of 8 to ~5% at 17. For the total cohort a very strong relationship was seen between RPE and %HR (linear regression r = 0.80, $P < 0.05$), RPE and $\%VO_2$ (linear regression r = 0.82, $P < 0.05$) and RPE and $[La^-]$ (quadratic regression r = 0.80).

<<Figure 1-3 and Table 2 near here>>

RPE and exercise mode

The %HR, $\%VO_2$ and $[La^-]$ as a function of RPE for running and cycling are shown in Figure 2. For %HR and $\%VO_2$, an interaction effect was observed between RPE and exercise mode (both, $P < 0.01$), as well as a main effect of exercise mode (~2 and 5% respectively, both, $P < 0.01$). Post-hoc tests revealed a higher %HR (ES=0.35-0.84) and VO_2 (0.52-1.30) for running compared with cycling at RPEs 8-13 but not at higher perceived exertions for %HR (ES = 0.04-0.61) or $\%VO_2$ (ES = 0.19-0.66). For $[La^-]$, there was no significant interaction effect between RPE and exercise mode ($P = 0.14$) or main effects of exercise mode ($P = 0.33$).

RPE and sex

The %HR, $\%VO_2$ and $[La^-]$ as a function of RPE for men and women are shown in Figure 3. For %HR and $\%VO_2$, no interaction effect was observed between RPE and sex ($P = 0.71$ and 0.63) but there was a main effect of sex (~1%, both, $P < 0.01$). Post-hoc tests revealed higher %HR at RPEs 12-13 (ES = 0.41 and 0.61, $P < 0.05$) and higher $\%VO_2$ and at RPEs 9,13 and 16 (ES = 0.68, 0.47 and 0.34, $P < 0.05$) for the women compared to men. For $[La^-]$, there was no significant interaction effect between RPE and sex ($P = 0.32$) or main effect of sex ($P = 0.22$).

DISCUSSION

We here present the associations between Borg's 6-20 RPE scale and the physiological markers %HR, $\%VO_2$ and $[La^-]$ in a cohort of 160 elite endurance athletes. The principle finding was a very large relationship between RPE and the physiological variables during the submaximal incremental test, but with substantial between-subject variation. During cycling, a lower %HR and $\%VO_2$ for a given RPE was found compared to running. This suggests that RPE is influenced by exercise mode during submaximal steady-state conditions, particularly at low intensities.

A very strong relationship was seen between RPE and %HR, $\%VO_2$ and $[La^-]$ for the total cohort. This is in line with Scherr, Wolfarth, Christle, Pressler, Wagenpfeil, Halle [8] who presented data based on 2,560 Caucasian men and women (untrained to athletes) and found a similarly strong relationship between RPE and HR or $[La^-]$ as in the present study (r = > 0.75). However, in contrast to Scherr, Wolfarth, Christle, Pressler, Wagenpfeil, Halle [8] we found that exercise mode (running vs cycling) influenced RPE at a given %HR and $\%VO_2$. The RPE ratings during cycling were higher than running at a given relative intensity (% of HR_{peak} or % of VO_{2max}), an effect that was most clear at low intensities (RPEs <13). Running and cycling activates many of the same muscles, but the contraction dynamics are different, with the knee-extensors, in particular, being more dominating in cycling than running [18,19]. Interestingly, when the cardiovascular stress is low, a greater proportion of the RPE ratings appear related to force generation [20]; therefore, we suggest that the relative muscle activation (percentage of maximal activation) of the knee-extensors during cycling was higher than for any active muscles during running, and thereby contributed to a higher RPE during cycling at the same % of VO_{2max}.

RPE is a well-used assessment tool, but we must acknowledge that psychophysiological mechanisms are still elusive. Moreover, how an individual interprets sensations during exercise will influence the ratings. An important issue is the distinction between effort and exertion [5,21]. If effort is “the mental or physical energy being given to a task”, exertion can be defined as “degree of heaviness and strain experienced in physical work” [5]. It seems reasonable to suggest that cycling and running are experienced differently, at least at lower intensities (RPEs <13) and the sum of perceived sensations cause the athletes to use the RPE scale differently during the two modes of exercise. This is in line with reports from sedentary individuals when comparing RPE during cycling and running [22,23].

In practice, the choice of exercise mode may matter, as the differences between running and cycling induced large coefficient of variations (up to 10-15% for %HR and $\%VO_2$) between athletes [**Figure 1**]. This implies that RPE is not a valid tool for detecting exercise intensity when changing between different exercise modes, particularly at low intensity. Also, when separating into running and cycling a variation of ~10% for %HR at low intensity was found. Consequently, at low intensity, we propose that other markers of intensity should be used to describe instant exercise intensity, for example heart rate, which seems well suited for monitoring intensity at prolonged constant low intensity exercise bouts [3]. However, at high intensity, it has been proposed that RPE (or session RPE) or respiratory frequency is a more sensitive marker than HR or $[La^-]$ [24,25]. We therefore recommend that athletes should manage a variety of tools to provide valid methods to plan, adjust, perform and evaluate training at different intensities and durations.

We found a slightly higher %HR and $\%VO_2$ at a given RPE for the women compared to men, which is supported by observations of others [26,27]. However, the reason for the sex difference is not clear and others have, conversely, reported no sex differences [11,28]. Nevertheless, the sex differences were small and possibly trivial (~1%). From a practical point of view, these differences are within the typical between-subject variation, indicating that individual variation should always be considered when using RPE for a group of athletes, and that several factors contribute to this variation.

Elite athletes frequently use a combination of different internal (subjective and objective) and external tools to plan, monitor, adjust, evaluate and individualize exercise intensity. To provide guidelines for coaches and athletes to develop individual zones, these tools are often structured into “intensity zones”. In the present study, we found that the $[La^-]$ in relation to %HR was markedly lower than presented in previous intensity scales intended for elite endurance athletes [2]. At a “moderate” intensity (HR of ~ 85% of peak, VO_2 of ~ 75% of max), $[La^-]$ was 2.5 ± 0.9 $mmol \cdot L^{-1}$ with RPE of 14 [**Table 2**], where previous scales imply a $[La^-]$ ranging from 2.5-4.0 $mmol \cdot L^{-1}$ at HR of 82-87%. These differences may be due to the very high level of the endurance athletes included in this study. Highly trained endurance athletes display a lower $[La^-]$ at a given %HR due to higher fractional utilization of VO_2 than recreational endurance athletes or non-endurance athletes [12]. The fiber type composition in our athletes is not known, but a high proportion of type I fibers seems to be a prerequisite in elite endurance athletes [29] and could therefore explain the low lactate levels at a given %HR in this study [30]**.**

Limitations

The present study investigated 5-min steady-state conditions in a group of elite endurance athletes. It is well documented that duration has a clear effect on RPE, despite constant HR or $[La^-]$ [24]. Thus, the short duration efforts used in the present study is highly relevant during testing but has clear limitations for longer sessions. For the running tests, 30 seconds breaks between stages were used to obtain [La-] due to practicality reasons, while the cycling tests were performed continuously. This short break might have influenced both the [La^-] and RPE between exercise modes [31]. However, the differences between exercise modes were mostly evident at low intensity, where breaks supposedly have the smallest effect. Thus, we believe that the break in running does not influence the interpretations of the results substantially. We used different subjects that were used to the specific exercise modes for the comparison between running and cycling, which could potentially influence the comparison between running and cycling. However, we believe that the large number of participants will reduce this uncertainty. Finally, we used the HR_{peak} found during testing of the VO_{2max} as an anchor for the RPE versus %HR values. However, we cannot state that this test is optimal to achieve the true HR_{max} and the %HR values versus RPE presented here could be slightly over-estimated. However, with an underestimating of HR_{max} of 3% (typical 5 beat per minute), the overestimating of %HR versus RPE would be ~2% and would not change the conclusions of the present study.

PRACTICAL APPLICATION

The present findings could serve as a framework for developing an overall guideline for intensity zones in elite endurance athletes. However, the systematic variation between exercise modes with different exercise intensities are important aspects to consider, indicating that intensity zones should always be individualized. Importantly, it cannot be assumed that one method of determining exercise intensity is necessarily equivalent to that derived using another method [1]. In some sports, external variables such as speed (or lap time) and power are commonly used in addition to the internal variables presented here. In practical settings, a combination of RPE, %HR and [La^-] are widely used tools for elite endurance athletes to plan, control or evaluate exercise intensity in various forms of exercise modes. However, we propose that these tools should be used differently according to exercise intensity: RPE is an important intensity assessment tool, but appears more reliable at high than low intensities (>70% of VO_{2max}), while HR and [La^-] could be used at low to moderate intensities.

CONCLUSION

Exercise mode influences RPE at a given %HR and %VO_2, with these differences increasing at lower intensities in a group of elite endurance athletes. Hence, athletes should manage different subjective and objective tools to plan, control and evaluate training based on the intensity and durations of workouts.

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Figure 1: Between-subject coefficient of variation (CV) (SD/mean) for the relative HR (%HR), relative oxygen uptake (% VO_2) and blood lactate concentration ([La$^-$]) as a function of rate of perceived exertion (RPE).

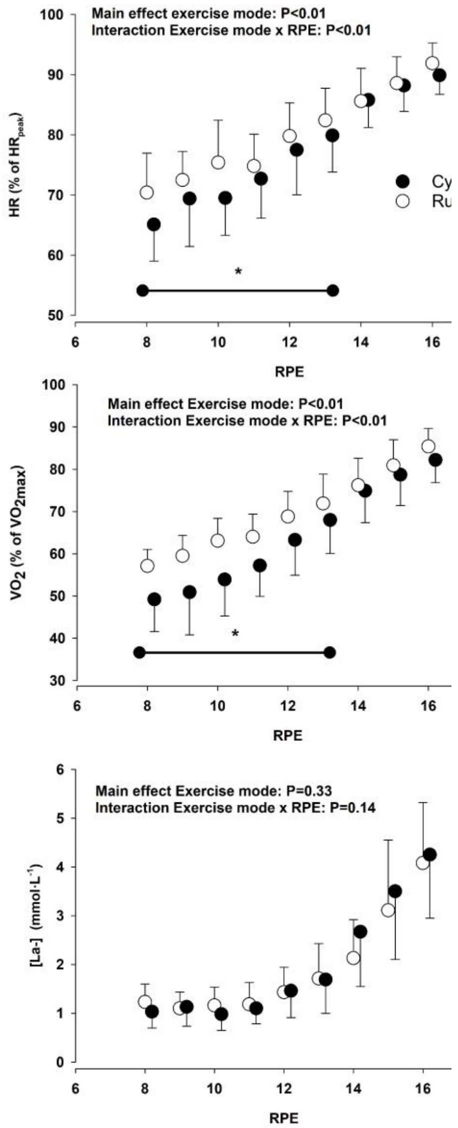

Figure 2: The relative HR (%HR), relative oxygen uptake (%VO_2) and blood lactate concentration ($[La^-]$) as a function of rate of perceived exertion (RPE) for running and cycling.

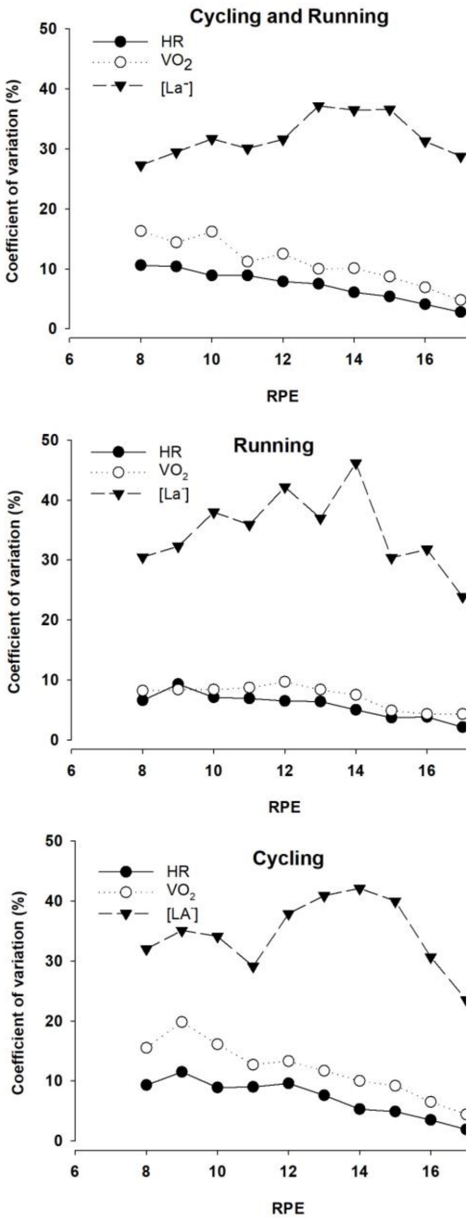

Figure 3: The relative HR (%HR), relative oxygen uptake (%VO_2) and blood lactate concentration ([La^-]) as a function of rate of perceived exertion (RPE) for men and women.

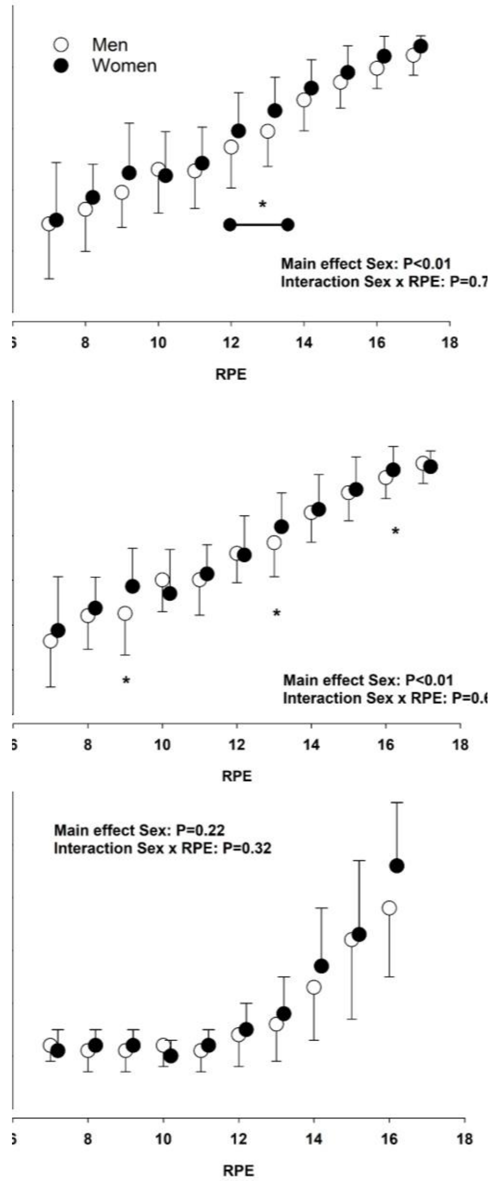

Table 1: Characteristics of the subject

	Men		Women	
	Running (n=44)	Cycling (n=47)	Running (n=32)	Cycling (n=37)
Age (yrs)	23 ± 4	20 ± 3	21 ± 2	25 ± 6
Weight (kg)	74 ± 7	74 ± 7	59 ± 4	60 ± 6
Height (cm)	181 ± 6	183 ± 5	168 ± 4	167 ± 6
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	77.1 ± 5.4	77.7 ± 6.0	64.9 ± 3.9	63.1 ± 5.6
HR_{peak} ($beat \cdot min^{-1}$)	193 ± 6	195 ± 7	193 ± 7	191 ± 9

Note: VO_{2max}: Maximal oxygen uptake, HR_{peak}; Peak heart rate during the VO_{2max} test. Data are mean ± SD.

Table 2: Reported rate of perceived exertion (RPE) and associated physiological variables.

RPE (6-20)	Description	HR (% of HR_{peak})	VO_2 (% of VO_{2max})	$[La^-]$ ($mmol \cdot L^{-1}$)
6		-	-	-
7	Very, very light	-	-	-
8		68 ± 7	53 ± 9	1.1 ± 0.3
9	Very light	71 ± 7	56 ± 8	1.1 ± 0.3
10		73 ± 6	58 ± 9	1.1 ± 0.3
11	Fairly light	74 ± 7	61 ± 7	1.1 ± 0.3
12		78 ± 6	66 ± 8	1.4 ± 0.5
13	Somewhat hard	81 ± 6	70 ± 7	1.7 ± 0.6
14		86 ± 6	75 ± 8	2.5 ± 0.9
15	Hard	88 ± 5	80 ± 7	3.3 ± 1.2
16		91 ± 5	84 ± 6	4.2 ± 1.3
17	Very hard	93 ± 5	86 ± 4	4.5 ± 1.3
18		-	-	-
19	Very, very hard	-	-	-
20		-	-	-

Note: Data from the total cohort (men and women, running and cycling together, N=160). Data are mean ± SD. HR; Heart rate, VO_2; oxygen uptake, $[La^-]$; capillary blood lactate concentrations.