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ORIGINAL ARTICLE

Treadmill running using an RPE-clamp model: mediators of perception and implications for exercise prescription

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Abstract

Purpose The mediators of the perception of effort during exercise are still unclear. The aim of the present study was to examine physiological responses during runs using a rating of perceived exertion (RPE)-clamp model at the RPE corresponding to the gas exchange threshold (RPE_{GET}) and 15% above GET ($RPE_{GET+15\%}$) to identify potential mediators and performance applications for RPE during treadmill running.

Methods Twenty-one runners ($\dot{V}O_{2max} = 51.7 \pm 8.3$ ml kg^{-1} min^{-1}) performed a graded exercise test to determine maximal oxygen consumption and the RPE associated with GET and GET + 15% followed by randomized 60 min RPE-clamp runs at RPE_{GET} and $RPE_{GET+15\%}$. Mean differences for $\dot{V}O_2$, heart rate (HR), minute ventilation ($\dot{V}_E$), respiratory frequency ($\mathcal{F}_R$), respiratory exchange ratio (RER), and velocity were compared across each run.

Results After minute 14, $\dot{V}O_2$, RER and velocity did not differ across conditions, but decreased across time ($p < 0.05$). There was a significant ($p < 0.05$) condition × time interaction for $\dot{V}_E$, where values were significantly higher during RPE-clamp runs at $RPE_{GET+15\%}$ and decreased across time in both conditions. There were no differences across condition or time for HR, and only small difference between conditions for $\mathcal{F}_R$.

Conclusions HR and $\mathcal{F}_R$ may play a role in mediating the perception of effort, while $\dot{V}O_2$, RER, and $\dot{V}_E$ may not. Although HR and $\mathcal{F}_R$ may mediate the maintenance of a perceptual intensity, they may not be sensitive to differentiate perceptual intensities at GET and GET + 15%. Thus, prescribing exercise using an RPE-clamp model may only reflect a sustainable $\dot{V}O_2$ within the moderate intensity domain.

Keywords Rating of perceived exertion · Exercise prescription · Running · Rpe-clamp

Abbreviations

GET	Gas exchange threshold
*v*GET	Velocity associated with GET
*v*GET + 15%	Velocity associated with 15% above GET
$\mathcal{F}_R$	Respiratory frequency
$\mathcal{F}_{Rmax}$	Maximal respiratory frequency
HR	Heart rate
HR_{max}	Maximal heart rate
LT	Lactate threshold
$(La^-)_b$	Blood lactate concentration
RCP	Respiratory compensation point
RER	Respiratory exchange ratio
RER_{max}	Maximal respiratory exchange ratio
RPE	Rating of perceived exertion
RPE_{max}	Maximal rating of perceived exertion
RPE_{GET}	RPE corresponding with GET

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$RPE_{GET+15\%}$	RPE corresponding with 15% above GET
$\dot{V}_E$	Minute ventilation
$\dot{V}_{Emax}$	Maximal minute ventilation
$vRPE_{GET}$	Velocity corresponding to the RPE at GET
$vRPE_{GET+15\%}$	Velocity corresponding to the RPE at 15% above GET
$\dot{V}O_2$	Oxygen consumption rate
$\dot{V}O_{2max}$	Maximal oxygen consumption rate
$v\dot{V}O_{2max}$	Velocity at $\dot{V}O_{2max}$

Introduction

In 1962, when Gunnar Borg developed and described a perceptual intensity scale for use during exercise, he triggered investigations into the relationships among physiological responses and the perception of effort that continues today (Borg 1962, 1998). The development of the Borg 6–20 and additional perceptual scales, such as the Borg CR-10 and OMNI scales (Borg 1998; Robertson 2004) and applications of these scales continues to add to our knowledge of perception and the mediators of perception during exercise. For example, Mielke et al. (2008) proposed a fatigue threshold that was based on the perception of effort, known as the physical working capacity at the rating of perceived exertion threshold (PWC_{RPE}), using the Borg 6–20 (PWC_{Borg}) and OMNI 0–10 (PWC_{OMNI}) scales (Cochrane et al. 2014; Mielke et al. 2008). In theory, the PWC_{RPE} estimates the maximal power output during cycle ergometry that can be maintained during continuous exercise without an increase in the perception of effort (Mielke et al. 2008). Thus, unique perceptually grounded thresholds may have applications as surrogates for physiological parameters, such as oxygen consumption ($\dot{V}O_2$) and heart rate (HR) to prescribe exercise.

Fatigue thresholds have been used to discriminate between fatiguing and non-fatiguing work, as well as demarcate the exercise intensity domains (moderate, heavy, or severe). For example, it has been suggested that the GET demarcates the moderate from heavy domains, while the RCP and critical power demarcate the heavy from severe domains (Bergstrom et al. 2012; Cochrane et al. 2014; Gaesser and Poole 1996). Furthermore, during continuous exercise, each domain is characterized by predictable patterns of responses for $\dot{V}O_2$, HR, and blood lactate concentration ($(La^-)_b$ (Enoka and Stuart 1992; Gaesser and Poole 1996; Poole et al. 1988). There is conflicting evidence, however, regarding the domain associated with a perceptual threshold, such as the PWC_{RPE}. For example, Mielke et al. (2008) reported that the PWC_{RPE} reflects an intensity demarcating the moderate from heavy exercise intensity domains, similar to GET. Exercise at GET has been defined as the highest power output that can be performed without a significant increase in $(La^-)_b$ (Gaesser and Poole 1996; Whipp 1987). In contrast, Bergstrom et al. (2012) reported no differences between PWC_{RPE} and RCP, which suggested an intensity demarcating the heavy and severe exercise intensity domains. Thus, the relative intensity associated with a perceptually based fatigue threshold and its relation to the moderate, heavy, and severe intensity domains remains unclear.

A number of studies have examined the physiological and perceptual responses during continuous, constant power output cycle ergometry (Dempsey 1986; Gaesser and Poole 1996; Garcin et al. 2008; Housh et al. 2000; Mielke et al. 2009; Poole et al. 1988). During fatiguing, constant power output exercise there are predictable, time-dependent patterns of responses for $\dot{V}O_2$, HR, RPE, respiratory frequency ($\mathcal{F}_R$), and minute ventilation ($\dot{V}_E$). There are, however, different patterns of responses for various physiological variables when continuous exercise is maintained at a constant physiological or perceptual parameter rather than power output or velocity. Exercise at a constant perceptual intensity (Cochrane et al. 2015a; Lander et al. 2009; Stoudemire et al. 1996), such as a constant rating of perceived exertion (RPE) based on the Borg (1970, 1982) or OMNI (Robertson et al. 2004) perceptual scales, has also resulted in dissociations among metabolic, cardiovascular, respiratory, and neuromuscular parameters during cycling and running exercise. Only one previous study (Stoudemire et al. 1996) has investigated physiological responses while running at a constant perceptual intensity in a trained population. No previous studies, however, have examined the metabolic, cardiovascular and respiratory patterns of responses during treadmill running at a constant RPE grounded using the GET.

A number of models have been proposed to explain physiological and perceptual responses during fatiguing and non-fatiguing exercise (Amann et al. 2010; Kaufman and Hayes 2002; Marcora 2009; Marcora and Staiano 2010). Of these, the corollary discharge model (Marcora 2009; Marcora and Staiano 2010), also known as the psychobiological model, and the exercise pressor reflex model (Amann et al. 2010; Kaufman and Hayes 2002) may help explain the unique patterns of physiological responses observed when exercise is clamped at a constant RPE. For example, the early findings of Marcora et al. (2010) theorized that there was a feed forward input from central command to the somatosensory and motor cortex creating an integration between cardiovascular responses, or other physiological responses, and the perception of effort during an exercise task. In contrast, the exercise pressor model (Amann et al. 2010; Kaufman and Hayes 2002) suggests that afferent feedback, specifically type III and IV thigh, leg, and/or respiratory muscle afferents may provide feedback to the brain centers responsible for the regulation of perceptual, cardiovascular, and respiratory responses during exercise. Although these models have been utilized to explain responses during constant power output and velocity exercise across exercise intensity domains in the past, a consensus regarding the efficacy of these models' ability to account for fatigue-related changes within these domains has yet to be reached. Exercise using an RPE-clamp model provides a unique method of applying these fatigue models to see how they may help to explain the formation and integration of effort perception during exercise.

The physiological and perceptual responses during constant power output or velocity exercise are well documented, but less is known about these responses at a constant perception of effort. The measurement of the perception of effort during exercise can be found in almost every aerobic-related performance study; however, there is conflicting evidence regarding the potential mediators of the perception of effort and which model(s) of fatigue may best account for physiological patterns of responses at a constant perception of effort using an RPE-clamp model. Therefore, the aims of this study were (1) to examine the metabolic ($\dot{V}O_2$ and RER), cardiovascular (HR), respiratory ($\dot{V}_E$ and $\mathcal{F}_R$), and velocity responses during continuous, RPE-clamp runs at the RPE corresponding to the velocity at the GET ($v\text{RPE}_{\text{GET}}$), and 15% above GET ($v\text{RPE}_{\text{GET+15\%}}$); and (2) to examine the implications for exercise prescription using rating of perceived exertion thresholds.

Methods

Experimental design

This study involved a total of four visits, separated by 24–48 h. During the first visit, subjects completed a screening and familiarization session, which included the completion of an informed consent, health history questionnaire, and familiarization on a motorized treadmill. During visit one, subjects were also familiarized with the Borg 6–20 rating of perceived exertion scale and given anchoring instructions according to standardized instruction and procedures (Borg 1982, 1998). Following standard instruction and procedures for Borg scale familiarization, subjects completed randomized runs on a treadmill using self-selected velocities to elicit goal RPE values of 9, 13, 15, 17, and 20 on the 6–20 scale.

During the second visit, the GET, maximal oxygen consumption rate ($\dot{V}O_{2\text{max}}$), velocities associated with GET (vGET), 15% above GET (vGET + 15%), and $\dot{V}O_{2\text{max}}$($v\dot{V}O_{2\text{peak}}$), RPE max (RPE_{max}), HR max (HR_{max}), respiratory frequency max ($\mathcal{F}_{R\text{max}}$), minute ventilation max ($\dot{V}_{\text{Emax}}$), and respiratory exchange ratio max (RER_{max}) were determined from an incremental treadmill test to exhaustion. The final two visits, in random order, consisted of a 60-min continuous run at a constant RPE corresponding to GET (RPE_{GET}) and a 60-min continuous run at a constant RPE corresponding to 15% above GET ($\text{RPE}_{\text{GET+15\%}}$). These intensities were chosen to represent the moderate (RPE_{GET}) and heavy ($\text{RPE}_{\text{GET+15\%}}$) exercise intensity domains (Cochrane et al. 2015a; Gaesser and Poole 1996). The subjects began the 60-min runs at the treadmill velocity that corresponded with RPE_{GET} or $\text{RPE}_{\text{GET+15\%}}$ and the velocity was adjusted every 30 s, as needed, to maintain the appropriate RPE. For some subjects, velocity adjustments during the first 6 min of exercise were necessary to attain the RPE that corresponded to RPE_{GET} or $\text{RPE}_{\text{GET+15\%}}$. After these initial adjustments to velocity, the RPE remained constant throughout the remainder of the 60-min runs. During each of the constant RPE runs, RPE, $\dot{V}O_2$, HR, $\mathcal{F}_R$, $\dot{V}_E$, RER, and velocity were recorded from min 7–60 to examine the patterns of changes across time.

Sample population, inclusion, and exclusion criteria

Twenty-one moderately trained runners (10 men and 11 women; mean ± SD age = 20.7 ± 1.1 years, height = 173 ± 7.6 cm, weight = 68.2 ± 9.5 kg) were recruited for this study. Moderately trained was defined as running 16 to 48 km week^{-1} most weeks during the 6-month period prior to testing. In addition, all subjects met $\dot{V}O_{2\text{max}}$ qualification criteria: ≥ 40 mL·kg^{-1} min^{-1} for women and ≥ 50 mL kg^{-1} min^{-1} for men (Thompson et al. 2014). All subjects were instructed to avoid exercising (both aerobically and lower body resistance training) the day prior to each test. Subjects were instructed to abstain from ergogenic aids throughout the duration of the study and to avoid stimulants, such as caffeine, for a minimum of 5 h prior to each experimental visit. Each subject performed the experimental runs at the same time of day (± 1 h). The subjects recruited did not have any known cardiovascular, pulmonary, metabolic, and/or history of coronary heart disease. This study was approved by the University Institutional Review Board for Human Subjects. All subjects completed a health history questionnaire and a signed written informed consent document on visit one prior to familiarization and testing.

Determination of the GET, 15% above GET, RCP and max values

Each subject performed an incremental treadmill test to exhaustion (Vision Fitness T9700s, Cottage Grove, WI, USA) to determine the GET, 15% above GET, $\dot{V}O_{2\text{max}}$, vGET, vGET + 15%, $v\dot{V}O_{2\text{max}}$, RPE_{max}, HR_{max}, $\mathcal{F}_{R\text{max}}$, $\dot{V}_{\text{Emax}}$, and RER_{max}, Prior to the test, each subject completed a 3 min warm-up on the treadmill at a self-selected velocity and 0% grade, followed by a 3 min passive recovery. Following the warm-up, each subject was fitted with a Parvo Medics 2-way breathing valve (Hans Rudolph 2700 breathing valve, Kansas City, MO, USA). Expired gas samples were collected and analyzed using a calibrated TrueMax 2400 metabolic cart (Parvo Medics, Sandy, UT, USA). The gas analyzers were calibrated with room air and gases of known concentration prior to all testing sessions. The O_2, CO_2, and ventilatory parameters were recorded breath-by-breath and expressed as 20 s averages. In addition, HR was recorded with a Polar Heart Rate Monitor (Polar Electro In., Lake Success, NY) that was synchronized with the metabolic cart. Heart rate was recorded continuously throughout the test and expressed as 20 s averages. Each subject was asked to give a rating of perceived exertion during the last 10 s of each min using the Borg 6–20 RPE scale (Borg 1998). The incremental test began at the treadmill velocity of 6.4 km h^{-1} and 0% grade. Thereafter, the velocity was increased by 1.6 km h^{-1} every 2 min to 14.4 km h^{-1} and 0% grade. Following the 14.4 km h^{-1} stage, the velocity was no longer increased, however, the treadmill grade was increased by 2% every 2 min until the subject could no longer maintain the running velocity and grasped the handrails to signal exhaustion. The $\dot{V}O_{2max}$ was defined as the highest 20 s average $\dot{V}O_2$ value recorded during the test which resulted in a plateau in oxygen consumption. The RPE_{max} was defined as the RPE taken at the end of the last full min completed during the incremental test to exhaustion. The HR_{max},$\mathcal{F}_{Rmax}$, $\dot{V}_{Emax}$, and RER_{max} were defined as the 20 s average of HR, $\mathcal{F}_R$, $\dot{V}_E$, and RER associated with $\dot{V}O_{2max}$ during the GXT.

The GET was determined using the V-slope method described by Beaver et al. (1986). The GET was defined as the $\dot{V}O_2$ value corresponding to the intersection of two linear regression lines derived separately from the data points below and above the breakpoint in the carbon dioxide produced ($\dot{V}CO_2$) versus $\dot{V}O_2$ relationship. The respiratory compensation point (RCP) was determined using the V-slope method described by Beaver et al. (1986) and was defined as the $\dot{V}O_2$ value corresponding to the intersection of two linear regression lines derived separately from the data points below and above the breakpoint in $\dot{V}_E$ versus $\dot{V}CO_2$ relationship (Beaver et al. 1986). The velocities performed at 0% grade (6.4–14.4 km h^{-1}), were plotted against $\dot{V}O_2$ and the regression equation derived was used to determine the $v\dot{V}O_{2max}$, vGET ($v\text{RPE}_{GET}$), and vGET + 15% ($v\text{RPE}_{GET+15\%}$) (Fig. 1).

Determination of the RPE at GET and RPE at 15% above GET

Velocities from the incremental test were plotted against RPE values and the regression equation derived was used to estimate the RPE at GET (RPE_{GET}) and RPE at GET + 15% ($RPE_{GET+15\%}$) (Fig. 1).

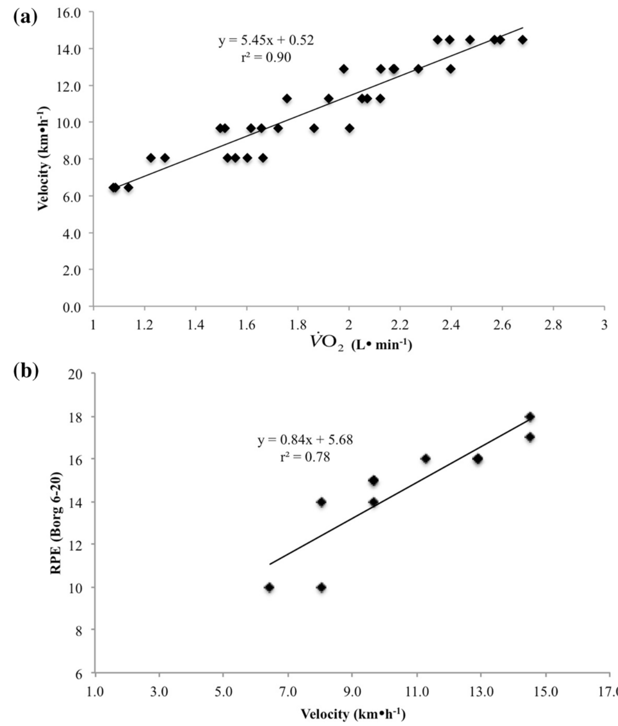

Fig. 1 Regression analysis for the determination of the velocity associated with the RPE at gas exchange threshold and 15% above gas exchange threshold used to start the RPE-clamped runs

RPE-clamp runs

Two, randomly ordered, 60 min RPE-clamp treadmill runs were performed at RPE_{GET} and $RPE_{GET+15\%}$ to determine the metabolic ($\dot{V}O_2$ and RER), cardiovascular (HR), respiratory ($\mathcal{F}_R$ and $\dot{V}_E$), and velocity responses at each intensity. Each subject completed a self-paced, 5 min warm-up, followed by 3 min of passive rest. For the RPE_{GET} and $RPE_{GET+15\%}$ runs, the initial intensities were set at the $v\text{RPE}_{GET}$ and $v\text{RPE}_{GET+15\%}$, respectively. Velocity was adjusted at the initiation of each exercise test to ensure that the goal RPE was reached within approximately 3–6 min. Both RPE-clamp runs were completed at a 0% grade and velocity was adjusted every 30 s or as needed to ensure that the pre-determined RPE remained constant throughout the run. Prior, unpublished pilot testing was completed to determine the velocity associated with a one-unit change in RPE (0.3–0.6 km h^{-1}). During each run, the $\dot{V}O_2$, HR, $\mathcal{F}_R$, $\dot{V}_E$, and RER values were collected, as previously described, and recorded as 20 s averages. Ratings of perceived exertion were assessed every 30 s or sooner if the subjects indicated their RPE had changed. Subjects were unaware of their goal RPE prior to the initiation of each run. After the subjects produced the goal RPE they were asked to maintain that feeling of effort and to run for an extended period of time (60 min). All subjects were able to maintain either RPE_{GET} or $RPE_{GET+15\%}$ for the 60 min duration.

Statistical analyses

The first 6 min of data collected during the 60-min runs were omitted to account for the initial physiologic adjustments to exercise as well as adjustments in velocity required to attain the RPE that corresponded to the RPE_{GET} and $RPE_{GET+15\%}$. The composite (mean of all subjects' data) responses for $\dot{V}O_2$, HR, $\mathcal{F}_R$, $\dot{V}_E$, RER, and velocity were examined for each RPE-clamp run. Each variable collected during the RPE-clamp runs was normalized as a percentage of the value corresponding to $\dot{V}O_{2max}$. The composite normalized responses were grouped into 7, 7 min Epochs (Epoch 1:7–13 min, Epoch 2:15–21 min, Epoch 3:23–29 min, Epoch 4:31–37 min, Epoch 5:39–45 min, Epoch 6:47–53 min, Epoch 7:55–60 min) from min 7–60. Polynomial regression analyses (linear and quadratic) were used to determine the patterns of responses for the composite, normalized $\dot{V}O_2$, HR, $\mathcal{F}_R$, $\dot{V}_E$, RER, and velocity versus time relationships during the RPE-clamp runs and to determine best model fit (Pedhauzur 1997). Coefficients of determination (r^2 and R^2) values were determined for all composite relationships. Further, six separate, 2×7 (Condition [RPE_{GET} vs. $RPE_{GET+15\%}$] × Time (Amann et al. 2008, 2010; Beaver et al. 1986; Bergstrom et al. 2012, 2015; Borg 1962, 1970)) repeated measures analyses of variance (ANOVAs) were used to analyze normalized $\dot{V}O_2$, HR, $\mathcal{F}_R$, $\dot{V}_E$, RER, and velocity. Follow-up 1-way repeated measures ANOVAs were completed to probe any significant main effects and/or interactions and Sidak–Bonferonni-corrected dependent samples *t* tests were completed where indicated by post-hoc tests. Greenhouse–Geisser corrections were applied when sphericity was not met according to Maulchy's Test of Sphericity and partial eta squared (η_p^2) and cohen's *d* (*d*) effect sizes (0.2 = small, 0.5 = moderate, 0.8 = high) were calculated for each ANOVA or significant initial *t* tests, respectively. All dependent variables, RPE-scales, and incremental testing procedures were previously found to be valid and reliable based on previous, unpublished data from investigations from the same laboratory using the same equipment, and from studies documented by Borg (1998) (Borg 1998, p 29–34; Bergstrom et al. 2012; Cochrane et al. 2015a, b; Mielke et al. 2008); test–retest reliability was not directly measured in the present study. An a priori alpha level of $p \le 0.05$ was used to qualify statistical significance for all analyses. All statistical analyses were conducted using IBM Statistical Package for the Social Sciences software (version 25.0, SPSS Inc. Chicago, Ill, USA).

Results

Model fit

The descriptive characteristics of the subjects ($n = 21$) and the mean ± SD and range for GET, GET + 15%, $vRPE_{GET}$, $vRPE_{GET+15\%}$, RPE_{GET}, $RPE_{GET+15\%}$, RPE_{GET} (%$\dot{V}O_{2max}$), and $RPE_{GET+15\%}$ (%$\dot{V}O_{2max}$) determined from the incremental test are included in Table 1. The results of the polynomial regression analyses for the composite responses during the RPE-clamp runs at RPE_{GET} indicated that there was no change in RPE ($p > 0.05$), but quadratic decreases for $\dot{V}O_2$ ($p < 0.01$, $R = 0.97$, $R^2 = 0.98$), $\dot{V}_E$ ($p = 0.01$, $R = 97$, $R^2 = 0.94$), and velocity ($p = 0.006$, $R = 0.99$, $R^2 = 0.99$). In addition, there were linear increases, and quadratic increases for HR ($p < 0.01$, $r = 0.98$, $r^2 = 0.95$) and $\mathcal{F}_R$ ($p = 0.019$, $R = 0.99$, $R^2 = 0.97$), respectively. The results of the polynomial regression analyses for the composite responses during the RPE-clamp at $RPE_{GET+15\%}$ runs indicated that there was no change in RPE ($p > 0.05$), but quadratic decreases for $\dot{V}O_2$ ($p < 0.01$, $R = 0.99$, $R^2 = 0.99$), $\dot{V}_E$ ($p = 0.01$, $R = 99$, $R^2 = 0.98$), and velocity ($p < 0.001$, $R = 0.99$, $R^2 = 0.99$). Heart rate exhibited a slight linear decrease ($p = 0.021$, $R = 0.78$, $R^2 = 0.62$), and there was a quadratic increase for $\mathcal{F}_R$($p = 0.01$, $R = 0.97$, $R^2 = 0.93$). Although all dependent variables indicated some degree of change across the RPE-clamp runs using polynomial analyses, complimentary ANOVA analysis indicated that model fit for HR and $\mathcal{F}_R$ may have been influenced by values at Epoch1.

Table 1 Descriptive characteristics of the subjects ($n = 21$)

Variable	Mean ± SD	Range
Age (year)	20.7 ± 1.1	19.0–23.0
Body mass (kg)	68.2 ± 9.5	51.8–85.0
$\dot{V}O_{2max}$ (mL kg^{-1} min^{-1})	51.7 ± 8.3	41.7–70.4
GET (mL kg^{-1} min^{-1})	38.1 ± 5.5	27.2–52.4
GET + 15% (mL kg^{-1} min^{-1})	43.8 ± 6.4	31.3–60.2
RCP (mL kg^{-1} min^{-1})[a]	48.8 ± 7.7	34.2–63.7
$vRPE_{GET}$ (km h^{-1})	12.7 ± 1.0	11.2–15.4
$vRPE_{GET+15\%}$ (km h^{-1})	14.4 ± 1.1	12.9–17.2
RPE_{GET}	15 ± 0.7	14–17
$RPE_{GET+15\%}$	17 ± 0.6	16–18
RPE_{GET} (%$\dot{V}O_{2max}$)	76 ± 6.0	62–85
$RPE_{GET+15\%}$ (%$\dot{V}O_{2max}$)	88 ± 7.0	72–98

RPE was based on the Borg 6–20 scale (Borg 1982)

[a]RCP data available for 18 of 21 subjects

Oxygen consumption, respiratory exchange ratio, minute ventilation, and velocity responses

For $\dot{V}O_2$, there was a significant ($p = 0.002, \eta_p^2 = 0.27$, small effect) condition × time interaction (Fig. 2). There was a significantly ($p = 0.001$, $d = 0.88$, large effect) lower normalized $\dot{V}O_2$ at Epoch1 for the RPE_{GET} condition versus $RPE_{GET+15\%}$. There were no significant ($p > 0.05$) differences for $\dot{V}O_2$ between the conditions at any of the other Epochs. Follow-up one-way repeated measures ANOVAs indicated that there were significant differences in $\dot{V}O_2$ across time for each condition (RPE_{GET}: $p < 0.001$, $\eta_p^2 = 0.45$, small effect; $RPE_{GET+15\%}$: $p < 0.001$, $\eta_p^2 = 0.65$, medium effect), and the pattern of change for $\dot{V}O_2$ differed as a function of condition (Fig. 2). For RPE_{GET}, pairwise comparisons revealed no significant differences among $\dot{V}O_2$ values from Epoch 1–Epoch 3 and no differences from Epoch 4–6. Significant decreases in $\dot{V}O_2$ were observed from Epoch 3 and 4 ($p = 0.013$) and between Epoch 6 and 7 ($p = 0.032$). For $RPE_{GET+15\%}$, $\dot{V}O_2$ at Epoch 1 was significantly higher than any other Epoch ($p < 0.0001$) and $\dot{V}O_2$ decreased significantly from Epoch1 through Epoch 3 ($p < 0.01$). There was no significant difference between Epoch 3 and 4 or Epoch 4 and 5. Furthermore, there were no significant changes in $\dot{V}O_2$ from Epoch 5–7, indicating a plateau in $\dot{V}O_2$ values after min 37.

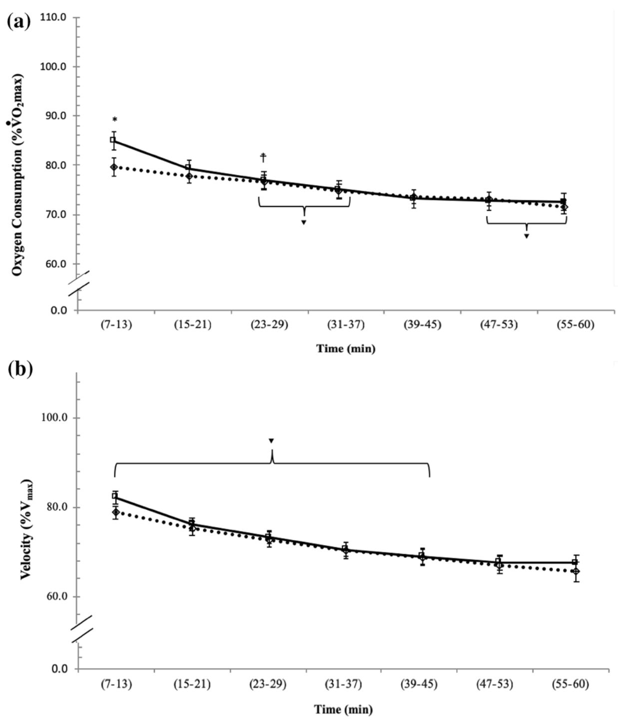

Fig. 2 RPE_{GET} (dotted line), $RPE_{GET+15\%}$ (dashed line) **a** For $\dot{V}O_2$, there was a significant ($p = 0.002$, $\eta_p^2 = 0.27$) condition × time interaction. Follow-up one-way RM ANOVAs indicated that there were significant differences in $\dot{V}O_2$ across time for each condition (RPE_{GET}: $p < 0.001$, $\eta_p^2 = 0.45$; $RPE_{GET+15\%}$: $p < 0.001$, $\eta_p^2 = 0.65$). For RPE_{GET}, Epoch 3 and 4 and Epoch 6 and 7 were significantly different (▾$p < 0.05$). For $RPE_{GET+15\%}$, $\dot{V}O_2$ at Epoch 1 was significantly higher than any other Epoch (*$p < 0.001$) and was higher for runs at $RPE_{GET+15\%}$ than at RPE_{GET} (*$p < 0.05$). $\dot{V}O_2$ decreased significantly from Epoch1 to Epoch 3 (‡$p < 0.01$). There were no significant differences between Epoch 3 and 4 or Epoch 4 and 5. There were no significant changes in $\dot{V}O_2$ from Epoch 5–7. **b** There was no significant condition × time interaction for velocity. There was no significant ($p > 0.05$) main effect for condition, but a significant main effect ($p < 0.001$, $\eta_p^2 = 0.85$) for time. Velocity significantly decreased (▾$p = 0.001$–0.01) from Epoch 1 to Epoch 5. There was no significant change in velocity from Epoch 6 to Epoch 7

There was a significant ($p < 0.001$, $\eta_p^2 = 0.25$, small effect) condition × time interaction for RER (Fig. 3). Respiratory exchange ratio was significantly greater during runs at $RPE_{GET+15\%}$ at Epoch 1 ($p < 0.001$, $d = 1.04$, large effect) and Epoch7 ($p = 0.006$, $d = 1.04$, large effect) vs. RPE_{GET} (Fig. 3). Follow-up one-way repeated measures ANOVAs indicated that there were significant differences in RER across time for each condition (RPE_{GET}: $p < 0.001$, $\eta_p^2 = 0.70$, medium effect; $RPE_{GET+15\%}$: $p < 0.001$, $\eta_p^2 = 0.61$, medium effect), and the pattern of change for RER differed as a function of condition (Fig. 3). For RPE_{GET}, pairwise comparisons revealed no difference in RER between Epoch1 and Epoch 2, but a significant decrease in RER from Epoch 2 through Epoch 5 ($p = < 0.001$–0.021). Respiratory exchange ratio was not different from Epoch 5 to Epoch 6 or from Epoch 6 to Epoch 7. For $RPE_{GET+15\%}$, RER significantly decreased from Epoch 1 through Epoch 3 ($p < 0.0001$) and again from Epoch 4 to Epoch 5 ($p = 0.02$). There were no differences for RER from Epoch 5 through Epoch 7 ($p = 0.73$–1.00).

There was a significant ($p < 0.001$, $\eta_p^2 = 0.53$, medium effect) condition × time interaction for $\dot{V}_E$ (Fig. 3). Minute ventilation was significantly greater during $RPE_{GET+15\%}$ runs at Epoch 1 ($p < 0.001$, $d = 1.48$, large effect), Epoch 2 ($p < 0.01$, $d = 0.74$, medium effect), Epoch 3 ($p < 0.05$, $d = 0.54$, medium effect), Epoch 4 ($p < 0.05$, $d = 0.44$, small effect), Epoch 5 ($p < 0.01$, $d = 0.60$, medium effect), Epoch 6 ($p < 0.01$, $d = 0.70$, medium effect), and Epoch 7 ($p < 0.05$, $d = 0.39$, small effect) compared to runs at RPE_{GET} (Fig. 3). Follow-up one-way repeated measures ANOVAs indicated that there were significant differences in $\dot{V}_E$ across time for each condition (RPE_{GET}: $p < 0.01$, $\eta_p^2 = 0.24$, small effect; $RPE_{GET+15\%}$: $p < 0.001$, $\eta_p^2 = 0.63$, medium effect), and the pattern of change for $\dot{V}_E$ differed as a function of condition (Fig. 3). For RPE_{GET}, pairwise comparisons revealed the only differences in $\dot{V}_E$ values occurred between Epoch 3 and Epoch 7 ($p = 0.025$) and Epoch 4 and Epoch 7 ($p = 0.028$). There were no other significant differences in $\dot{V}_E$ during runs at RPE_{GET}. There

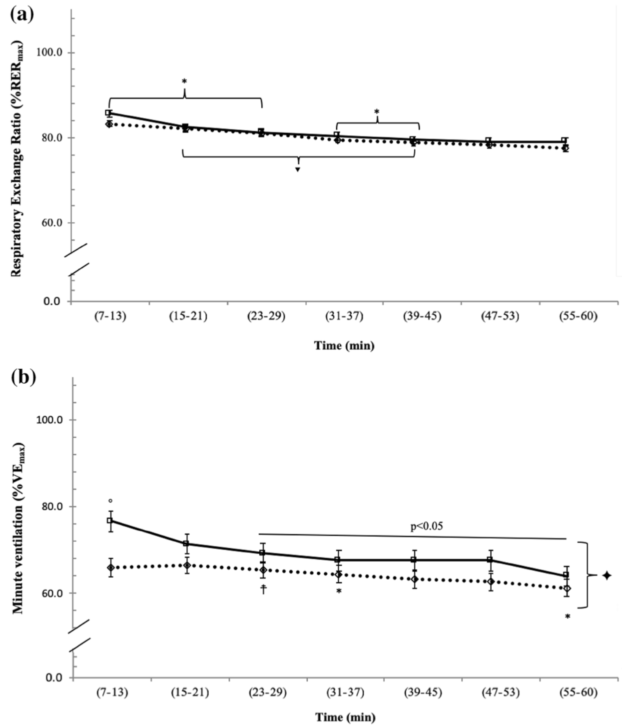

Fig. 3 RPE_{GET} (dotted line), $RPE_{GET+15\%}$ (dashed line) **a** There was a significant ($p<0.001$, $\eta_p^2=0.25$) condition × time interaction for respiratory exchange ratio (RER). For RPE_{GET}, there was no difference in RER between Epoch 1 and Epoch 2, but a significant decrease in RER from Epoch 2 to Epoch 5 (▼$p<0.05$). For $RPE_{GET+15\%}$, RER significantly decreased from Epoch 1 to Epoch 3 (*$p<0.01$) and again from Epoch 4 to Epoch 5 (*$p<0.01$). **b** There was a significant ($p<0.001$, $\eta_p^2=0.53$) condition × time interaction for minute ventilation ($\dot{V}_E$). Follow-up one-way RM ANOVAs indicated that there were significant differences in $\dot{V}_E$ across time for each condition (RPE_{GET}: $p<0.01$, $\eta_p^2=0.24$; $RPE_{GET+15\%}$: $p<0.001$, $\eta_p^2=0.63$). For RPE_{GET}, the only differences in $\dot{V}_E$ values occurred between Epoch 3 and Epoch 7 (‡$p<0.05$) and Epoch 4 and Epoch 7 (*$p<0.05$). At $RPE_{GET+15\%}$, Epoch 1 was significantly higher than any other Epoch(∘$p<0.05$). There was no difference between Epoch 2 and Epoch 3, but significant decreases in $\dot{V}_E$ from Epoch 3 through Epoch 7 ($p<0.05$). $\dot{V}_E$ values were significantly higher at each Epoch during runs at $RPE_{GET+15\%}$ (✦$p<0.05$)

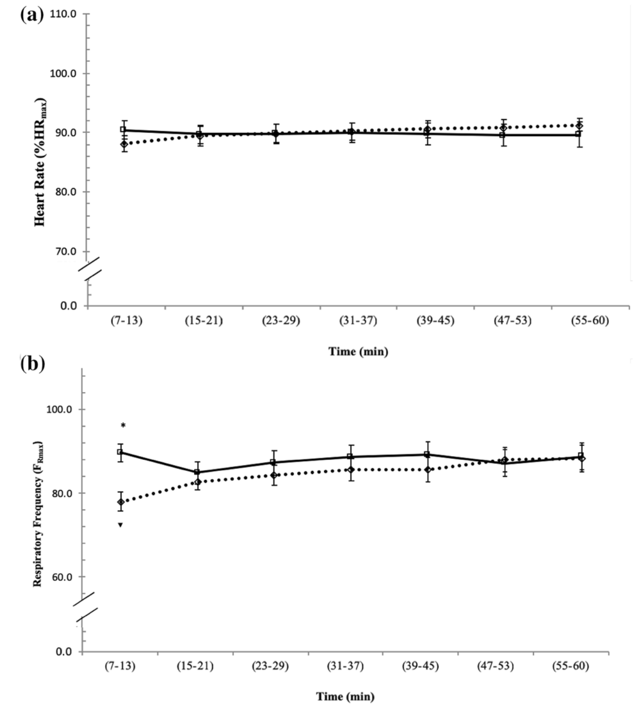

Fig. 4 RPE_{GET} (dotted line), $RPE_{GET+15\%}$ (dashed line) **a** For heart rate (HR), there was no significant ($p>0.05$) condition × time interaction, no significant main effect for condition or time. **b** For respiratory frequency ($\mathcal{F}_R$) there was a significant ($p<0.05$, $\eta_p^2=0.24$) condition × time interaction. Respiratory frequency was significantly less (▼$p<0.001$, $\eta_p^2=0.41$) at Epoch 1 vs. Epoch 2 through 7 during RPE_{GET} runs, but there were no differences across time at $RPE_{GET+15\%}$ runs. $\mathcal{F}_R$ at Epoch 1 was significantly higher (*$p<0.05$) during runs at $RPE_{GET+15\%}$ than at RPE_{GET}

was more variability for $\dot{V}_E$ during runs at $RPE_{GET+15\%}$. Epoch 1 was significantly higher ($p<0.001$) than any other Epoch. There was no difference between Epoch 2 and Epoch 3, but significant decreases in $\dot{V}_E$ from Epoch 3 through Epoch 7 ($p=0.003$–0.022).

There was no significant condition × time interaction ($p>0.05$) for velocity, nor was there a main effect for condition ($p>0.05$) (Fig. 2). There was, however, a significant main effect for time ($p<0.001$, $\eta_p^2=0.85$, large effect). Velocity significantly decreased across each Epoch ($p=0.01$–0.001), with each velocity being significantly higher in the preceding Epoch up until Epoch 6, where there was no significant difference between velocity at Epoch 6 and Epoch 7 (min 47–60).

Heart rate and respiratory frequency

There was no significant condition × time interaction ($p>0.05$, $\eta_p^2=0.002$), main effect for condition ($p>0.05$, $\eta_p^2=0.03$), or main effect for time ($p>0.05$, $\eta_p^2=0.09$) for HR (Fig. 4). There was a significant condition × time interaction ($p=0.005$, $\eta_p^2=0.24$, small effect) for $\mathcal{F}_R$ (Fig. 4). At Epoch 1, $\mathcal{F}_R$ was higher ($p=0.001$, $d=1.66$, large effect) during runs at $RPE_{GET+15\%}$ only at Epoch1. Follow-up one-way repeated measures ANOVAs for each condition across time indicated that there were significant differences for $\mathcal{F}_R$ values during runs at RPE_{GET} ($p<0.001$, $\eta_p^2=0.41$, small effect), but not at $RPE_{GET+15\%}$ ($p=0.30$, $\eta_p^2=0.06$). For runs at RPE_{GET}, Epoch 1 was significantly less ($p=0.001$–0.01) than every other Epoch. There were no significant differences among any of the other Epochs after Epoch 1.

Discussion

In the present study, RPE_{GET} and $RPE_{GET+15\%}$ were 76 ± 6.0% (range 62–85%) and 88 ± 7.0% (range 72–98%) of $\dot{V}O_{2max}$, respectively. It has been reported that the GET of endurance-trained individuals, typically, occurs between 70 and 80% of $\dot{V}O_{2peak}$ (Bergstrom et al. 2012; Davis 1985; Gaesser and Poole 1996). In addition, 18 of 21 subjects in the present study exhibited an RCP, while three subjects did not manifest the non-linear increase in $\dot{V}_E$ as a function of $\dot{V}CO_2$ typical of the RCP (Beaver et al. 1986) during the incremental test to exhaustion. For those subjects who did manifest an RCP, $RPE_{GET+15\%}$ was at an intensity below the RCP (91.7 ± 4.8% of RCP) and, therefore, within the heavy exercise intensity domain. It has been reported that in endurance-trained athletes, the RCP typically occurs at 80–90% of $\dot{V}O_{2max}$ (Cooper and Storer 2005). All subjects maintained the RPE-clamp runs RPE_{GET} and $RPE_{GET+15\%}$ from minute 7 until minute 60, which suggested that perceptually anchored intensities within the moderate and heavy exercise intensity domains were sustainable for at least 60 min of treadmill running among endurance-trained runners. These findings were similar to those of Cochrane et al. (2015b) who reported that the RPE_{GET} and $RPE_{GET+15\%}$ intensities were sustainable for at least 60 min of cycle ergometry. Thus, the perceptually anchored intensities used in the present investigation were: (1) similar to those of previous studies (Bergstrom et al. 2012; Cochrane et al. 2015b; Davis 1985; Gaesser and Poole 1996); (2) associated with moderate and heavy intensity work in aerobically-trained runners; (3) sustainable for at least 60 min of treadmill running.

Physiological responses when running using an RPE-clamp model

Previous studies have examined the physiological and perceptual responses during continuous, constant power output cycle ergometry and constant velocity treadmill running (Carter et al. 2002; Dempsey 1986; Gaesser and Poole 1996; Kindermann et al. 1979; Poole et al. 1988; Steed et al. 1994) within both the moderate and heavy exercise intensity domains. For example, increases in HR, $\dot{V}O_2$, $\dot{V}_E$, core temperature (T_{core}), and blood lactate concentration ($(La^-)_b$) have been reported during sustained (≥ 30 min) constant workload exercise at 50–70% of $\dot{V}O_{2max}$, and it was hypothesized (Martin et al. 1979; Nybo and Nielsen 2001; Stoudemire et al. 1996) that a rise in RPE may be mediated by time-dependent changes in these physiological variables. The typical patterns of responses for perceptual and physiological variables during constant workload exercise differ when a variable (cardiovascular, respiratory, or metabolic) other than workload (power output or velocity) is held constant (Bergstrom et al. 2015; Kindermann et al. 1979; Martin et al. 1979; Ribiero et al. 1986). Thus, the patterns of responses for physiological and perceptual variables are dependent upon the exercise intensity domain in which the exercise is performed as well as the variable used to anchor the exercise intensity.

The results of the present study indicated that when exercise is clamped at a set perceptual intensity, the pattern and mean responses for physiological and velocity related variables, such as $\dot{V}O_2$, RER, $\dot{V}_E$, and workload were dissociated or un-coupled from the perception of effort. Oxygen consumption RER and $\dot{V}_E$ tracked reductions in velocity across time, but the patterns of response for these variables were influenced by their anchor intensity. Whereas $\dot{V}O_2$ values were significantly higher and demonstrated a large effect size, indicating a very meaningful difference, during the first Epoch for runs starting in the heavy domain ($RPE_{GET+15\%}$), no differences occurred after min 13. In addition, there was a slow decline in oxygen consumption across time during runs within the moderate domain while values plateaued from min 37–60 during runs at $RPE_{GET+15\%}$, ending in the same relative $\dot{V}O_2$ value as runs in the lower perceptual condition. Respiratory exchange ratio was also dissociated from RPE but exhibited general decreases across time in both conditions. These responses displayed large effect sizes indicating that the changes in velocity to maintain RPE had a robust effect on RER values. The responses for $\dot{V}_E$ showed more variability between the moderate (RPE_{GET}; 15 ± 0.7) and heavy ($RPE_{GET+15\%}$; 17 ± 0.6) conditions from min7 to min60 and all but one significant comparison demonstrated a medium to large effect size, indicating that the difference across both condition and time represented meaningful differences under the current experimental constrains. In addition, $\dot{V}_E$ displayed a marked decrease after Epoch 1, followed by another significant drop beginning at Epoch 3 (23 min) and ending at Epoch 7 (60 min). Previous studies (Cochrane et al. 2015a, b; Stoudemire et al. 1996) have demonstrated the uncoupling of $\dot{V}O_2$, RER, and $\dot{V}_E$ during cycling (Cochrane et al. 2015a, b) and running (Stoudemire et al. 1996) exercise when a perceptual threshold is used to clamp intensity. For example, Cochrane et al. (2015a; b), reported that $\dot{V}O_2$, RER, and $\dot{V}_E$ were coupled to reductions in power output during cycle ergometry at a perceptual intensity corresponding to GET and 15% above GET. The findings of the present study were similar to those of Cochrane et al. (2015a, b) for $\dot{V}O_2$, RER, and $\dot{V}_E$ during both moderate and heavy intensity runs. Although $\dot{V}O_2$, RER, and $\dot{V}_E$ were uncoupled from RPE during the present study, their tracking of velocity was similar to that reported in previous studies (Ribeiro et al. 1986; Bergstrom et al. 2015; Cochrane et al. 2015a, b) regardless of the variable used to maintain intensity. In addition, the findings of the present study indicated that clamping exercise at a constant RPE elicited intensity-dependent alterations in the patterns of response for oxygen consumption, substrate utilization, and respiratory measures related to volume of air moved per breath that demonstrated the runners were able to differentiate intensities while only using RPE as a source of feedback. Thus, mechanisms underlying oxygen consumption, substrate utilization, and the quantity of air moved into and out of the lungs, signifying the elimination of CO_2 from alveoli may not be direct mediators of perceptual responses, but were directly impacted by alterations in workload (velocity) required to regulate exercise at a constant RPE.

The findings of the present study differed from responses observed during cycling exercise using an RPE-clamp model at similar intensities (Cochrane et al. 2015a, b). It was hypothesized (Cochrane et al. 2015b), that the dissociations among RPE and HR, $\dot{V}O_2$, RER, and power output during RPE-clamp cycling supported the hypothesis that metabolic and cardiovascular-related variables do not solely mediate the perception of effort. This finding was also substantiated by Stoudemire et al. (1996), who suggested that "HR is not a significant mediator of respiratory-metabolic exertional signals" (114, p 493). The findings of Cochrane et al. (2015a; b) and Stoudemire et al. (1996) are in contrast to the current study which found no significant change in HR over time during RPE-clamped runs at RPE_{GET} or $RPE_{GET+15\%}$. In the current study, HR responses mirrored the patterns of responses for perception of effort across both conditions, and there were no significant differences in mean HR responses between or across conditions at each time Epoch. These results may indicate that cardiovascular responses did influence the integration of effort perception and the maintenance of a perceptual intensity during prolonged running exercise.

As observed with HR responses, $\mathcal{F}_R$ responses tracked the perception of effort across RPE-clamped runs at both RPE_{GET} and $RPE_{GET+15\%}$. In addition, despite differences in relative perceptual intensities, there were no significant differences among $\mathcal{F}_R$ values during the RPE_{GET} runs from Epoch 1 through Epoch7, and Epoch 2 through Epoch7 during $RPE_{GET+15\%}$ runs. These findings indicated that $\mathcal{F}_R$ was most effected by the initial velocities during the initiation of exercise during the heavy intensity runs ($RPE_{GET+15\%}$) as demonstrated by the large effect size ($d=1.66$) at Epoch1, but after min 13, $\mathcal{F}_R$ tracked RPE for the remainder of the trial. The only physiological variable that has previously been shown to track the perception of effort during clamped RPE exercise was $\mathcal{F}_R$ (Cochrane et al. 2015a, b). It was suggested (Cochrane et al. 2015b), that mechanisms underlying respiratory mechanics may mediate the perception of effort during cycling-specific exercise at moderate and heavy intensities. Although no current study has completed an Epoch by Epoch analysis during RPE-clamped cycling exercise, it can be hypothesized that the similar tracking of HR and $\mathcal{F}_R$ during clamped RPE exercise modalities may indicate that mechanisms underlying chemical and mechanical changes associated with the cardiovascular and respiratory systems (Amann et al. 2008, 2010) feedback to the central nervous system. This feedback is used to integrate a requirement for the maintenance of a perceptual feeling of exertion, and that maintenance response may not have the capacity to vary physiological responses during RPE-clamped exercise associated with the upper boundary of the moderate exercise intensity domain and within the heavy domain.

The inability of HR and $\mathcal{F}_R$ to reflect differences between RPE-clamp intensities may be explained by the $\dot{V}O_2$ responses observed during runs at RPE_{GET} and $RPE_{GET+15\%}$. Although a set perceptual intensity was being maintained by the runners, they dropped out of the heavy intensity domain after the first 14 min of exercise. The subjects began runs at $RPE_{GET+15\%}$ ($88\pm7\%\dot{V}O_{2max}$) and ended at approximately 74% of $\dot{V}O_{2max}$, or the same end intensity associated with 60 min runs at RPE_{GET}. Maintaining treadmill running at $RPE_{GET+15\%}$, therefore, resulted in the subjects moving from the heavy exercise intensity domain to the moderate domain over the course of 60 min. Because RPE differed across conditions, the initial workload to elicit prescribed RPE goals experienced by the runners may have caused early onset fatigue in the $RPE_{GET+15\%}$ condition, causing them to require a greater reduction in velocity at the early stages of exercise. After which, they were able to stabilize their perceptual level, but may have still been experiencing fatigue-related effects from minute 0–14 and, therefore, felt that the exercise was harder despite a similar $\dot{V}O_2$ from Epoch 2–7. Taken together, these findings indicate that although HR and $\mathcal{F}_R$ tracked the consistency of perceptual responses across time, they were not able to differentiate between perceptual intensities. Thus, there appear to be associations among the mechanisms related to cardiovascular and respiratory responses and the perception of effort during exercise, but these mechanisms are not able to explain subtle differences in perceptual intensities across time.

It has been hypothesized (Cochrane et al. 2015a, b), that since $\mathcal{F}_R$ was the only variable found to track perception (RPE) during moderate and heavy intensity cycle ergometry, there are similar underlying mechanisms related to the respiratory muscles (Amann et al. 2008, 2010; Kaufman and Hayes 2002; Kaufman 2010; Nicolò et al. 2016) that may mediate the perception of effort and $\mathcal{F}_R$ during prolonged cycling exercise at a constant RPE. Similarly, Nicolò et al. (2016) reported that the perception of effort and $\mathcal{F}_R$ increased in a similar fashion during a range of self-paced cycle ergometry, and that $\mathcal{F}_R$, not $\dot{V}_E$, $\dot{V}O_2$, or HR, may be the best correlate of RPE when subjects are completing self-paced exercise. The findings of the present study and those of previous studies indicated that there is evidence that different physiological variables may or may not mediate the perception of effort, and that the correlation among these variables differs as a function of the exercise mode, intensity, and the variable used to anchor the exercise task. Furthermore, $\mathcal{F}_R$ may be the most consistent correlate of RPE during RPE-clamp and self-paced exercise.

Fatigue models and their relationship to RPE

The findings of the present study supported the original theory of Borg (1982), who referred to the perception of effort as the integration of various factors that lead an individual to form a subjective feeling related to the hardness of the task. Some of these factors include cardiovascular, respiratory, and metabolic related variables (Borg 1962, 1982). The hypothesis of Borg (1962) is further supported by the concept of redundancy (Brooks et al. 2000; Kaufman and Hayes 2002), and the applicability of various models of fatigue as a function of exercise intensity and controlled parameter may be explained by this concept. Redundant control mechanisms associated with the regulation of ventilatory and cardiovascular responses at rest and during exercise are designed "…so that if one system fails, there will be at least one other—and probably several other systems to take over" (Brooks et al. 2000, p 255). Thus, there may be multiple factors that influence not only physiological responses, but also perceptual responses during exercise.

An analog of the concept of redundancy can contribute to our understanding of exercise regulation and fatigue. As we see dissociations among physiological variables that are dependent upon which method of controlling exercise intensity is used, redundancy may explain the inability of any one fatigue model to fully account for the dynamic cardiovascular, respiratory, and perceptual responses when controlling for a specific input parameter. As inputs to the control system are varied, the relationships among output variables are also ultimately altered. The dissociations for $\dot{V}O_2$, RER, $\dot{V}_E$, HR, $\mathcal{F}_R$, and RPE in the present study and in previous studies (Cochrane et al. 2015a, b; Stoudemire et al. 1996) support the concept of redundancy. Thus, there may be no single, current model of fatigue that can be applied consistently to self-paced or RPE clamped exercise.

Implications for exercise prescription

Psychophysical scales, such as the Borg 6–20 scale (Borg 1962, 1970, 1982), are often used to examine the relationship between one's subjective feelings of exercise intensity and physiological variables such as HR and $\dot{V}O_2$ during incremental or sustained workload exercise tasks. A construct of the use of RPE scales is that they provide an indicator of "the degree of heaviness and strain experienced in physical work" (Borg 1998), as well as the amount of mental or physical energy experienced by the subject performing an exercise task. The American College of Sports Medicine has advocated the use of RPE scales as a way of monitoring the progression of an incremental test to exhaustion and to prescribe and monitor exercise intensity throughout the course of a workout (Garber et al. 2011; Thompson et al. 2014; Utter et al. 2001). Previous studies (Dantas et al. 2015; Dunbar et al. 1992; Eston and Williams 1988) have tested the application of RPE to monitor exercise using self-paced time trials and self-selected RPE production trials, where the subject selects the work intensity to produce a specified RPE rating, during cycle ergometry and treadmill running. For example, Eston and Williams (1988) reported that the Borg 6–20 scale could be used to provide a reliable frame of reference for the production of moderate and intense levels of effort during cycling exercise in healthy men and women. In addition, Dantas et al. (2015) demonstrated that RPE was strongly correlated to $(La^-)_b$, and suggested that this relationship could be used to prescribe exercise using RPE values that corresponded to blood lactate thresholds (2 mmol and 4 mmol). Thus, there is evidence that under specific conditions, RPE may be used in place of physiological measurements ($(La^-)_b$ or $\%\dot{V}O_{2Peak}$) when prescribing exercise.

In the present study, the composite % of $\dot{V}O_{2Peak}$ at RPE_{GET} was 78 ± 3.7% and the subjects started and finished the runs at 81 ± 9% and 74 ± 6%, respectively. The composite % of $\dot{V}O_{2Peak}$ at $RPE_{GET+15\%}$ from the incremental test was greater than RPE_{GET} (90 ± 4.7%), and the subjects started at a higher, relative intensity (88 ± 7% vs. 81 ± 9) but ended at the same relative intensity (74 ± 7%) as those during runs at RPE_{GET}. These findings supported those of Cochrane et al. (2015b) in that anchoring exercise at RPE_{GET}, but not $RPE_{GET+15\%}$, produced % of $\dot{V}O_{2max}$ values that were consistent with the intensity corresponding to the incremental test, and that this intensity remained within ± 4% throughout 60 min of treadmill exercise anchored at RPE_{GET}. Thus, prescribing exercise at a constant RPE may only be applicable for 20 min or less at intensities higher than GET, but sustainable for 60 min at intensities similar to GET. Future studies are needed to investigate the efficacy of prescribing exercise using an RPE-clamp model.

Conclusions

The results of the present study indicate that there are dissociations among the patterns of response for physiological variables related to metabolic rate, respiration, and cardiovascular function when running exercise is maintained at a constant perception of effort within the moderate and heavy exercise intensity domains. These responses varied from those observed during RPE-clamp cycling exercise and suggested that mechanisms related to HR and $\mathcal{F}_R$ may play a role in the mediation of the perception of effort. In addition, the results suggested that using an RPE based threshold for running exercise associated with the anaerobic threshold (GET) may have future exercise applications for aerobic prescription, such as during tempo training. Furthermore, the use of an RPE threshold such as RPE_{GET} was shown to be sustainable for 60 min within the moderate intensity domain while maintaining a $\dot{V}O_2$ (within 4%) of its target GET intensity corresponding to the incremental test.

Author contributions KCS and TJH conceived and designed the research. KCS, NDM, CMS, ECH conducted the experiments. KCS wrote the manuscript. TJH, NDM, CMS, ECH read and approved manuscript.

Compliance with ethical standards

Conflict of interest The authors report no conflicts of interest related to this study.

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