The Relationship Between Rating of Perceived Exertion and Muscle Activity During Exhaustive Constant-Load Cycling

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Key words
- neuromuscular fatigue threshold
- fatigue
- prolonged exercise

Abstract

The aims of this study were to verify the relationship between rating of perceived exertion (RPE) and electromyography (EMG) increases during exhaustive constant-load cycling bouts and, to compare and to correlate the power outputs corresponding to perceived exertion threshold (PET) and neuromuscular fatigue threshold (NFT). 11 men completed 3–4 different exhaustive constant-load cycling bouts on a cycle ergometer, being RPE and EMG measured throughout the bouts. The linear regression of the $\text{RPE}_{\text{slope}}$ and $\text{EMG}_{\text{slope}}$ against the power output identified the PET and NFT intensity, respectively. There was a significant relationship between $\text{RPE}_{\text{slope}}$ and $\text{EMG}_{\text{slope}}$ ($R^2=0.69$; $P<0.01$). However, the linearity of $\text{RPE}_{\text{slope}}$ ($R^2=0.93\pm0.07$) was significantly higher ($P<0.001$) than $\text{EMG}_{\text{slope}}$ ($R^2=0.63\pm0.25$). In addition, the $\text{RPE}_{\text{slope}}$ and $\text{EMG}_{\text{slope}}$ were related to time to exhaustion ($r=-0.59$ and $r=-0.60$; $P<0.001$). There was no significant difference ($P=0.42$) between PET (201.5±27.9W) and NFT (210.3±22.6W) and they were significantly correlated ($r=0.78$; $P=0.005$). Therefore, the RPE and EMG increases during exhaustive constant-load cycling bouts are related and, PET and NFT intensities are similar and closely associated.

Introduction

The rating of perceived exertion (RPE) is a psychophysiological variable that has been used to monitor and prescribe the intensity of different exercise modes for healthy individuals [2,5,7,9,18], children and elders [21], obese [35], and diseased people [15]. The RPE is related to physiological variables such as heart rate, oxygen consumption and blood lactate concentration [4,8,28]. In addition, RPE responses during resistance training [27,28] and endurance performance [19] are associated with the degree of skeletal muscle recruitment measured by electromyography activity (EMG).

Studies have shown that cycling at fixed or self-selected intensity (moderate exercise intensity) and fixed exercise duration may not change EMG activity [12,29]. However, exercise performed at high intensity and till exhaustion constantly requires additional and progressive muscle fiber recruitment to compensate the force loss associated with muscle fatigue, thereby increasing EMG activity [10,36]. The recruitment of additional muscle fibers may also be associated with an increased RPE [14], and it has been suggested that the response of the latter is regulated by the central nervous system [32,46,48]. In addition, several studies have shown a linear increase in the EMG [10,24] and RPE [37–40] during exhaustive constant-load exercise, which allows the estimation of their increasing rates ($\text{EMG}_{\text{slope}}$ and $\text{RPE}_{\text{slope}}$, respectively), however, the relationship between these 2 variables has not been investigated. The confirmation of the significant relationship between $\text{EMG}_{\text{slope}}$ and $\text{RPE}_{\text{slope}}$ during exhaustive constant-load exercise will reinforce RPE as a simple tool to predict and monitor exercise intensity, and, it may also be considered an indirect measure of muscle activity during such exercise bouts.

Using similar protocol and linear regression, the $\text{RPE}_{\text{slope}}$ and the $\text{EMG}_{\text{slope}}$ have been used to determine the perceived exertion threshold (PET) and the neuromuscular fatigue threshold (NFT), respectively [36,37]. The PET seems a reliable aerobic index [39] due to its similarity and high correlation with critical power ($r=0.87$–0.98) and maximal oxygen consumption steady state intensity ($r=0.92$) [37–40], as well as the bias and limits of agreement between PET and critical power are acceptably low [39]. On the other

accepted after revision
June 01, 2010

Bibliography
DOI http://dx.doi.org/10.1055/s-0030-1255108

Int J Sports Med 2010; 31: 683–688

ISSN 0172-4622

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hand, NFT has been related to anaerobic threshold (r = 0.82; 0.92) [34,36] and rowing performance (r = 0.96) [31], although its validity as an aerobic index has been questioned [31,44]. Theoretically, both PET and NFT represent similar phenomena, that is, a steady state of perceptual and neuromuscular responses (i.e., zero slope), respectively, throughout long lasting exercise [36,39,40]. Nevertheless, the PET and NFT have not been directly compared. If these methods predict similar exercise intensities, PET should clearly have an advantage over NFT, since simpler procedures are required to evaluate exercise performance. Furthermore, PET can be used to evaluate training effects and control the exercise intensity during fitness programs. For instance, the reduction of the RPE_{slope} of an individual at a given power output would indicate improvement in aerobic performance. Finally, although the EMG may also be useful for such practical application, RPE is more attractive since technical devices are not required to perform the tests.

Therefore, the aims of this study were: (1) to verify the relationship between RPE and EMG increases during exhaustive constant-load cycling bouts and (2) to compare and correlate the power outputs corresponding to PET and NFT.

Materials and Methods

▼

Participants

11 physically active (~2–3 recreational exercise sessions per week) non-smoking healthy men (23.4 ± 5.2 years; 73.6 ± 5.1 kg; 177.8 ± 7.0 cm) participated in this study. They were instructed to refrain from vigorous activities and ingestion of beverages containing alcohol or caffeine in the 24-h prior to each test. This study was approved by the local Institutional Research Ethics Committee and has been performed in accordance with the ethical standards of this journal [22]. In addition, the participants were informed about the procedures and risks before giving written consent to participate in the study.

Experimental design

This study was conducted within a 3-week period, in which participants reported to the laboratory on 3–4 occasions with a minimum of 48-h between sessions. They were all fully familiarized with the tests and experimental procedures, since they had already participated in previous studies using similar protocols. The tests consisted of 3–4 different high-intensity constant-load bouts performed randomly until exhaustion on a cycle ergometer. The number of tests completed varied according to participants' availability to return to the laboratory (4 tests: n = 8; 3 tests: n = 3). Such a variation in the number of sessions was allowed due to 3–4 predictive tests which did not have influence on the PET and NFT determination [10,24,38]. During all predictive tests, RPE, EMG and power output were recorded to determine PET and NFT.

Predictive tests

The tests were performed on an electronically braked cycle ergometer (Quinton Corival 400, Lode Medical Technology, Groningen, Holland). Seat and handlebar height were individually recorded during the first test and reproduced in the subsequent ones. Prior to each test, participants warmed up by cycling at 50 W for 3 min followed by 2 min of passive recovery. During the tests participants were instructed to maintain a cadence of 60 rpm. Test interruption (i.e., exhaustion) occurred when participants were unable to sustain a cadence greater than 55 rpm for a period of 5 s, despite strong verbal encouragement. To accomplish the exhaustion time target (i.e., ~1–15 min), we have empirically determined in our laboratory that relative power outputs should lie within 2.5 and 4.5 W per kilogram of participant's body mass. This procedure was adapted from Hill et al. [24]. Nevertheless, in 3 participants one of the predictive tests lasted longer than 15 min. All tests were completed approximately at the same time of the day. No feedback concerning the power output or elapsed time was provided to the participants during the tests.

Determination of perceived exertion threshold (PET)

The Borg 6–20 scale [5] was displayed in front of the participants during all tests. Instructions about reporting their RPE were given before each predictive test, with anchoring as follows: "number 7 represents unloaded cycling while number 19 indicates an exertion similar to exhaustive cycling". Participants were asked to accurately report their whole body feelings (i.e., overall RPE) [17] every 30 s period. The RPE scores generated from these tests were plotted against time (independent variable), and linear regression indicated the slope coefficient (RPE_{slope}) (▶ **Fig. 1a**). The PET intensity was defined as the *x*-intersection of the regression line for the power output from the predictive tests and its respective RPE_{slope} [37–40] (▶ **Fig. 1b**).

Determination of neuromuscular fatigue threshold (NFT)

Active bipolar (20 mm center-to-center) surface electrodes (TSD 150TM, Biopac Systems®, CA, USA – common mode rejection ratio: 95 dB) were used to measure vastus lateralis muscle activity from the participant's dominant leg. The electrodes were positioned between the motor point and the proximal tendon [23]. Inter-electrode impedance was minimized by careful skin shaving and alcohol cleaning. The reference electrode was placed over the anterior iliac crest. Ink markings were made around the electrodes so that they could be placed in a constant position for all tests. The EMG signal was amplified (MP150 Electromyogram Amplifier, Biopac Systems Inc, Santa Barbara, Ca. USA) and applied a frequency band filter ranging from 20 to 500 Hz. The EMG signal was digitized with a sampling frequency of 2 000 Hz and processed by calculating the root-mean-square (RMS) every 5 s (AcqKnowledge 3.8.1TM software, Biopac Systems®, CA, USA). The EMG was normalized to the initial 5 s of each trial. The NFT was estimated by determining the increase rate for the total exercise period (EMG_{slope}) for each predictive test [36] (▶ **Fig. 1c**). The slopes were plotted against their respective power outputs. The NFT was obtained as the *x*-intercept of the linear regression [10] (▶ **Fig. 1d**).

Statistics

Descriptive statistics are presented as mean ± standard deviation, unless otherwise stated. Least square linear regression was used to fit the data in order to estimate EMG_{slope} and RPE_{slope}. Data normality and homogeneity of variance were confirmed. The coefficients of determination between EMG_{slope} and RPE_{slope} were used to identify their relationship. The t-test for paired samples was used to compare PET and NFT power outputs and the coefficients of determination (R^2) associated with data fitting. Pearson product-moment was used to verify the correlations between PET and NFT, as well as among EMG_{slope} and RPE_{slope} with performance (i.e., time to exhaustion). The bias

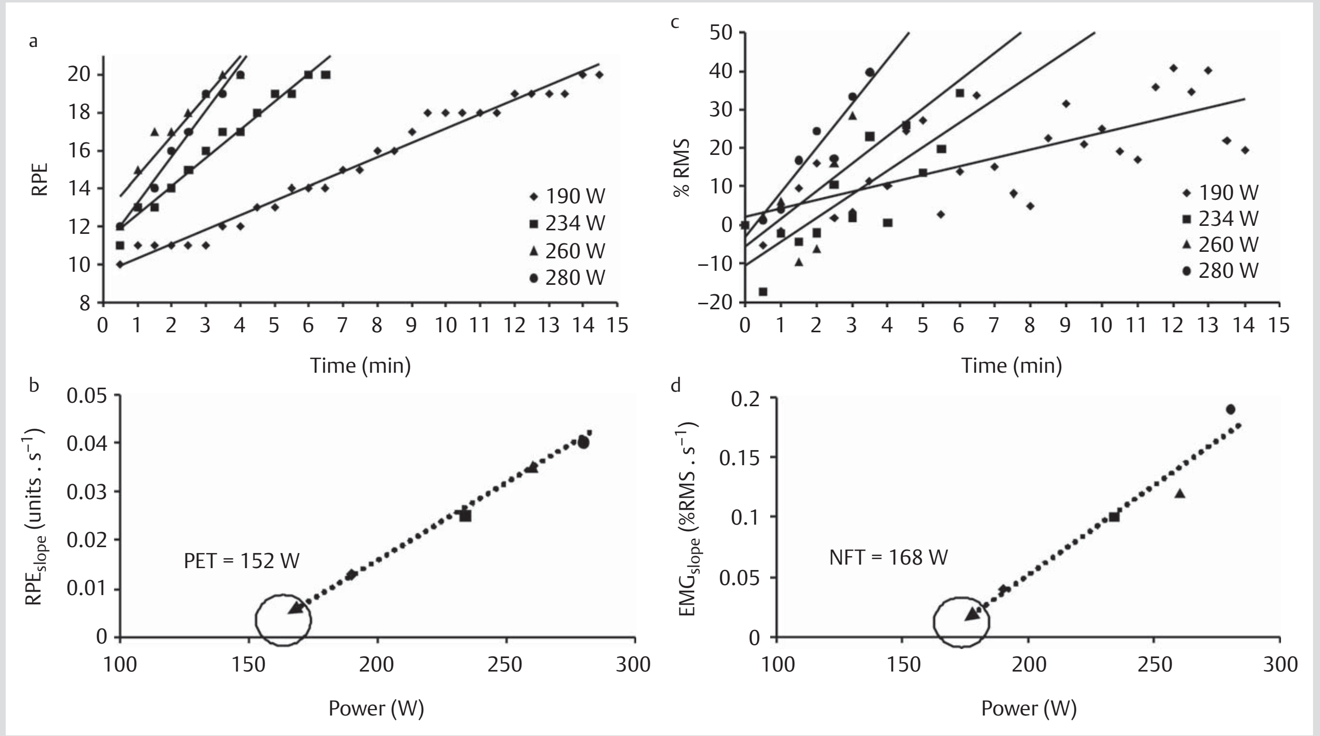

Fig. 1 Estimation procedure of perceived exertion threshold (PET) and neuromuscular fatigue threshold (NFT) of a participant. **a**: Ratings of perceived exertion (RPE) plotted as a function of time for 4 workloads. **b**: Rate of increase of RPE (RPE$_{slope}$) from 1a plotted for each of the 4 intensities and the projected slope zero (PET). **c**: Percentage of root-mean-square (%RMS) plotted against time. **d**: Rate of increase of %RMS (%RMS. s^{-1}) from 1c plotted for each of the 4 intensities and the projected slope zero (NFT).

Table 1 Rate of increase of ratings of perceived exertion (RPE$_{slope}$) and of electromyographic activity (EMG$_{slope}$), perceived exertion threshold (PET), neuromuscular fatigue threshold (NFT), coefficients of determination (R^2) and correlation of RPE$_{slope}$ and EMG$_{slope}$ with time to exhaustion.

	RPE$_{slope}$ (units.s^{-1})	R^2	EMG$_{slope}$ (%RMS.5s^{-1})	R^2	PET (W)	R^2	NFT (W)	R^2
mean	1.50	0.93	1.56	0.63*	201.5	0.91	210.3	0.94
SD	0.97	0.07	1.24	0.25	27.9	0.11	22.6	0.04
relationship with time to exhaustion	−0.59†		−0.60†					

* significantly different from R^2 of RPE$_{slope}$ ($P<0.001$)

† significant correlation ($P<0.01$)

and limits of agreement (LoA) of PET and NFT were calculated using Bland-Altman analysis [3]. The significance level was set at $P<0.05$. Data were analyzed using a statistical software (SPSS for Windows, version 17).

Results

The power outputs performed by the participants in the predictive tests ranged from 190 to 340 W and time to exhaustion from 105 to 1 500 s. **Table 1** depicts the results of RPE$_{slope}$, EMG$_{slope}$, PET, NFT and their respective coefficient of determination. The linearity of RPE$_{slope}$ was significantly higher than for EMG$_{slope}$ ($P<0.001$) and a significant relationship between these variables was found ($R^2=0.69$; $P<0.01$), as shown in **Fig. 2**.

Table 2 shows the individual power outputs for NFT, PET, and their respective standard errors (SE) and R^2. No significant difference was observed between PET and NFT (201.5 ± 27.9 W and 210.3 ± 22.6 W, respectively; $P=0.42$), and their SE and R^2. In addition, a significant relationship between PET and NFT was found ($r=0.78$; $P<0.01$). Furthermore, **Fig. 3** depicts the results of the Bland-Altman 95 % LoA analysis between PET and NFT. The bias was −8.9 ± 17.5 W and the LoA ranged from 25.4 W (+1.96 SD) to −43.1 W (−1.96 SD), evidencing a good agreement.

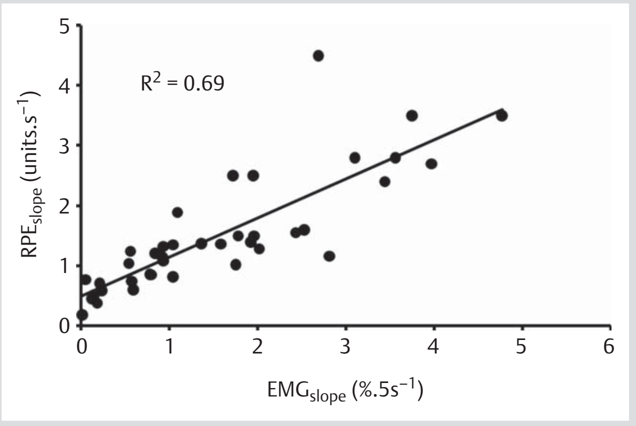

Fig. 2 Relationship between the increasing rate of ratings of perceived exertion (RPE$_{slope}$) and electromyography (EMG$_{slope}$) for all workloads ($P<0.01$).

Table 2 Individual power output (P) of neuromuscular fatigue threshold (NFT) and perceived exertion threshold (PET), and their respective standard error (SE) and coefficient of determination (R^2).

	NFT			PET		
n	P (W)	SE (W)	R^2	W	SE	R^2
1	193.6	9.2	0.95	212.1	14.0	0.95
2	222.1	12.1	0.98	209.0	25.9	0.92
3	196.3	13.7	0.98	175.1	53.0	0.79
4	192.5	17.5	0.90	200.7	9.2	0.97
5	213.7	24.9	0.93	225.4	16.6	0.96
6	227.1	7.8	0.96	211.7	16.1	0.90
7	244.2	12.1	0.92	237.8	10.8	0.94
8	168.7	19.8	0.89	151.8	4.6	1.00
9	232.6	25.2	0.47	203.0	33.8	0.61
10	197.8	7.8	0.98	161.2	14.0	0.97
11	227.0	16.5	0.89	229.6	7.8	0.97
mean	210.5	15.2	0.89	210.6	18.7	0.91
SD	22.4	6.2	0.15	27.8	14.1	0.11

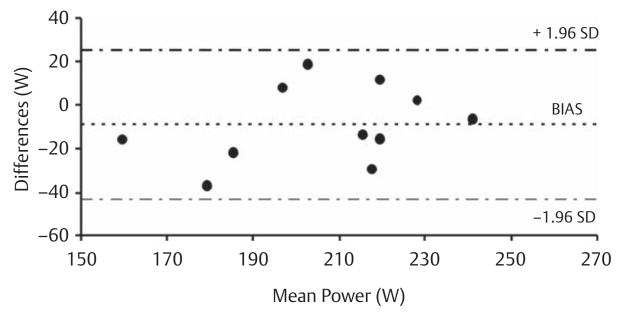

Fig. 3 Bias ± LoA 95 % accessed by Bland-Altman analysis from perceived exertion threshold and neuromuscular fatigue threshold.

Discussion

The main findings of the present study confirmed our hypothesis that there is a significant relationship between the EMG_{slope} and RPE_{slope} during exhaustive constant-load cycling bouts, and that both variables predicted a similar intensity for fatigueless prolonged exercise (NFT and PET, respectively). Although other physiological variables have shown a relationship with RPE [4,16,27], this is the first study to show a significant relationship between EMG_{slope} and RPE_{slope} during exhaustive constant-load cycling and similarity of the NFT with PET power outputs.

The force loss caused by the fatigued muscle fibers during the constant-load high intensity exercise requires additional motor units' recruitment [10,36], which seems associated with increased RPE [14]. Our data corroborate these studies, evidenced by the significant relationship between EMG_{slope} and RPE_{slope} ($R^2=0.69$) during the exhaustive constant-load cycling. While previous studies have shown a corresponding increase in the RPE and EMG during resistance exercise [25,27] and cycling using different loads [30], a correlation was only shown during leg extension exercise ($r=0.55$) [13] in which the fatiguing effect was not analyzed. The present study expands those findings, demonstrating that the rates of EMG and RPE increase are also correlated during constant-load cycling to exhaustion.

There are a number of different explanations for the link between RPE and EMG responses during fatiguing exercise. Marcora and colleagues [32,33] suggested that the RPE during exercise is generated by corollary discharges of the motor commands to the active skeletal muscles. According to this explanation efferent copies of these motor commands are sent to the sensory areas of the brain from where the RPE is processed. In this model, RPE is therefore part of the feedforward control during exercise. On the other hand, Noakes [42] proposed that the increased skeletal muscle recruitment is the main cause of several physiological responses. The consequences of the increased metabolic demand are sensed by the brain via feedback, thereby raising the RPE [41]. The discussion about whether the feedback influences RPE response is beyond the scope of this study. However, our results are compatible with both theoretical models since EMG_{slope} and RPE_{slope} were strongly related.

The RPE and EMG responses have been shown to increase linearly until exhaustion during high intensity constant-load exercise [36,43]. In order to identify the best fatigueless intensity predictor, the present study compared the linearity of both variables in function of time and showed that the RPE_{slope} ($R^2=0.93$) was significantly higher than the EMG_{slope} ($R^2=0.63$), however, no differences between their SE and R^2 were found when used to estimate PET and NFT. Despite the differences in data fitting to linear function, these variables present a significant relationship ($R^2=0.69$) and similar correlations to time to exhaustion ($r=-0.59$ and -0.60, respectively).

However, one may question the reliability of the vastus lateralis muscle as a representative muscle of the quadriceps, since different EMG responses have been reported for similar cycling exercising protocols [11,20]. Although a number of studies reported an increased EMG activity of the vastus lateralis during constant-load high intensity cycling exercise and used this to determine NFT [6,20,25,37,45] it was recently reported that vastus lateralis and vastus medialis EMG activity did not change during similar exercise protocol [11]. These contrasting results may be explained based on different pedal cadence between studies [26], since competitive cyclists have a certain pedaling skill regarding the positive recruitment of knee flexors (i.e., biceps femoris muscle) up to the higher cadences, which would contribute to a decrease in peak pedal force and alleviate muscle activity for the knee extensors (e.g., vastus lateralis and vastus medialis muscle) [47]. Then, a lower pedal cadence in the present study (~60 rpm) compared with the other one (95 ± 8 rpm) [11] may explain the increased EMG activity of the vastus lateralis muscle in our study.

In the present study, the NFT and PET power outputs were similar, significantly correlated ($r=0.78$; $P<0.01$) and showed acceptable agreement (bias $= -8.9 \pm 17.5$ W). These findings can be explained by the close association between the EMG_{slope} and the RPE_{slope} and similar procedures for their estimations. While NFT has been criticized as it overestimates well established aerobic capacity indices [10,31,44], PET is equivalent to critical power and highly correlated with ventilatory threshold [40]. However, the estimation of the fatigueless intensity by NFT using EMG requires expensive equipment and personal expertise. In contrast, PET can provide similar power output estimation by using subjective responses from a single scale, even though familiarization to the procedure might be required.

One limitation when estimating the fatigueless intensity by PET, as well as NFT, is the number of exhaustive tests (~3–4) needed throughout different days. However, identifying changes in a single RPE_{slope} on a specific power output might help to monitor training effects. For instance, after a training period, the RPE_{slope}

during an exhaustive constant-load cycling exercise can decrease when compared with a previous one. In such a case, the individual may perceive less effort when exercising at the same intensity, indicating fitness improvement. However, this suggestion has to be experimentally investigated for further conclusions. Moreover, Nakamura and colleagues [39] proposed a method to estimate PET by non-exhaustive bouts, at which the $\text{RPE}_{\text{slope}}$ ranging from 14–17 of the Borg's scale provided similar intensities when compare to PET with all RPE responses. These aspects may improve the practical application of $\text{RPE}_{\text{slope}}$ and PET.

In conclusion, our results presented a significant relationship between the increase in RPE and EMG activity during exhaustive constant-load cycling bouts. In addition, PET and NFT showed similar power outputs, standard errors and coefficients of determination. Then, both techniques seem to be a good predictor of the fatigueless intensity for prolonged exercise, although the PET can be more attractive since technical devices (i. e., EMG) are not required to perform the tests. The data provided new information regarding the physiological meaning of RPE and PET, and how these parameters are related to neuromuscular aspects during exercise. Furthermore, RPE may be useful to control intensity during exhaustive cycling exercise, providing an indirect measure of the muscle activity.

Acknowledgements

We would like to thank Professor Timothy D. Noakes for assistance with the editing of the manuscript and Dr. Mara Patrícia Traina Chacon-Mikahil for providing the facilities. This study was funded by National Council of Scientific and Technological Development (CNPq), Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES), and FAPESP (04/12589-0).

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