

Speed and Grade Increment During Cardiopulmonary Treadmill Testing: Impact on Exercise Prescription

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Abstract

Background: Maximal oxygen uptake ($VO_2\max$) and both first (VT_1) and second (VT_2) thresholds have been used as reference points for exercise prescription in different populations.

Objective: We aimed to test the hypothesis that exercise prescription, based on VTs determined by treadmill cardiopulmonary exercise testing (CPET), is influenced by the rate of increase in treadmill workload.

Methods: Nine healthy individuals underwent two CPETs, followed by two sessions of submaximal exercise, both in randomized order. For the “speed” protocol, there was an increment of 0.1 to 0.3 $km \cdot h^{-1}$ every 15s. The “grade” incremental protocol increased 1% every 30s and 0.1 $km \cdot h^{-1}$ every 45s. This was followed by submaximal exercise sessions lasting 40min at an intensity corresponding to heart rate (HR) between the VT_1 and VT_2 .

Results: The “speed” protocol resulted in higher VT_1 ($p = 0.01$) and VT_2 ($p = 0.02$) when compared to the “grade” incremental protocol, but there was no effect on $VO_2\max$. The target HR for the submaximal exercise sessions was higher in the “speed” protocol compared to the “grade” incremental protocol ($p < 0.01$) and remained stable during the two steady-state exercise sessions. Blood lactate remained stable during the submaximal exercise sessions, with higher values observed during the “speed” protocol than those “grade” incremental protocol ($p < 0.01$).

Conclusions: Compared to a grade-based protocol, a speed-based protocol resulted in higher VT_1 and VT_2 , which significantly affected cardiorespiratory and metabolic responses to prescribed exercise intensity in healthy young adults. (Int J Cardiovasc Sci. 2019;32(4):374-383)

Keywords: Cardiovascular Diseases; Exercise Test; Exercise Tolerance; Oxygen Consumption.

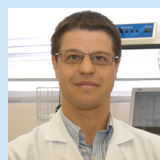
Introduction

Cardiopulmonary exercise testing (CPET) provides valuable diagnostic and prognostic information for healthy subjects and patients with cardiovascular disease^{1,2} and has long been used in the assessment of

athletic performance, as well as for various research applications.³ CPET responses have also been extensively used for the prescription of exercise intensity during aerobic training.⁴ In this context, maximal oxygen uptake ($VO_2\max$) and, both first (VT_1) and second (VT_2) thresholds, have been used as reference points for

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exercise prescription among both athletes and patients with cardiovascular disease.⁴⁻⁷

Tests based on ramp protocols are recommended for CPET because they generally provide a linear increase in VO_2 relative to workload, particularly when performed on the cycle ergometer.⁸⁻¹¹ The VT_1 and the VT_2 occur at similar VO_2 , independent of the rate of increase in exercise intensity on the cycle ergometer^{12,13} and the same is true for the determination of the VT_1 on the treadmill.¹⁴ Regardless of differences between cardiorespiratory fitness measured on a cycle ergometer and a treadmill, the choice of the ergometer may influence VT_1 determination.^{14,15}

In the Americas, the treadmill is the exercise mode of choice in clinical settings.^{1,2,16} When using the treadmill, it can be difficult to achieve a linear response in metabolic rate because of the walk-run transition,¹⁷ the rate of increase in speed and grade,¹⁸⁻²⁰ or handrail support and its effect on economy.¹⁴ Moreover, there is little information available on the effects of different treadmill ramp protocol increments on the detection of the VT_1 and VT_2 .^{14,15}

Changes in speed and/or grade may be used to develop an appropriate treadmill ramp protocol in efforts to make the work rate increments as linear as possible.²⁰ In this regard, work rate increments can have notable effects on the response to exercise due to the disproportionate interaction between muscle activation,²¹⁻²³ kinematic variables related to gait, and oxygen uptake (VO_2) kinetics;²⁴ and each of these factors can significantly influence VO_2 during exercise. Moreover, the impact of the type of increment during CPET performed on a treadmill with regard to exercise prescription has not been previously studied. Therefore, this study was conducted to compare the effects of two treadmill ramp protocols on the detection of VT_1 and VT_2 . We applied one protocol mainly using speed increments and another using mainly grade increments. In addition, we evaluated the steady-state response to exercise prescription based on the measured ventilatory thresholds from the two protocols.

Material and methods

Participants

Four male and five female subjects, aged 29 ± 6 years [95% CI = 25; 33], height 170 ± 8 cm [95% CI = 165; 175], and weight 65 ± 8 kg [95% CI = 60; 71], participated in

the study. All subjects were active and otherwise healthy as determined by medical history, physical examination, and resting and exercise electrocardiograms. None were taking medications. The subjects did not vary their activity levels during the testing period. All rights and privileges were honored in accordance with an established human subject's protocol, and informed consent was obtained. The ethics committee of the institution approved the protocol.

Protocol

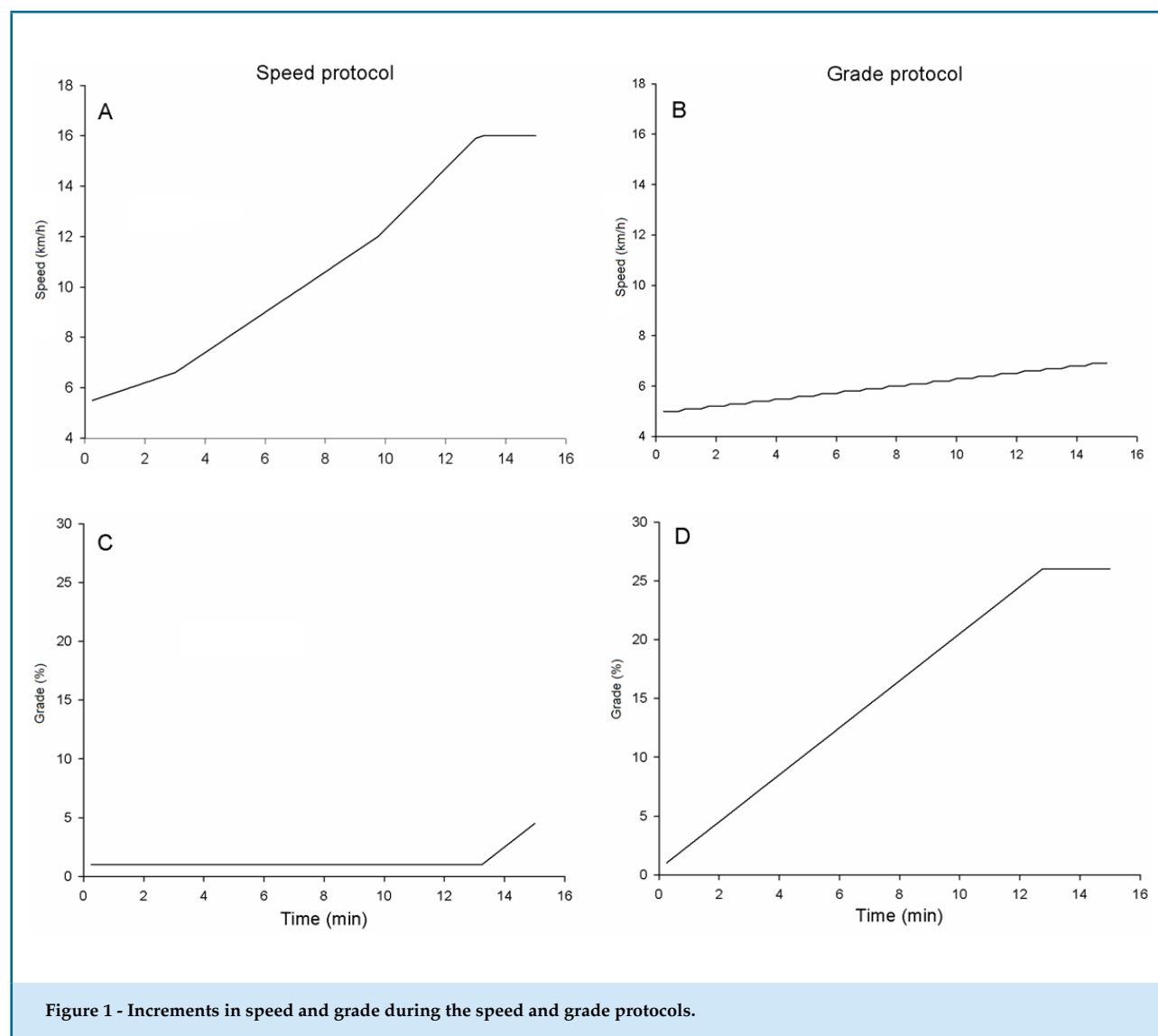
The protocol included two maximal incremental CPETs and two submaximal exercise sessions, performed on different days; the type of increment was chosen in random order. All tests were performed in a comfortable laboratory environment, with a minimum of 48 hours between tests. The CPET system underwent gas and volume calibration before each exercise test. No handrail support was allowed during the tests.³ The randomization of protocols was performed by an independent researcher using the software Rx 64 version 13. The protocol randomized for the first incremental CPET was the same for the first submaximal exercise session.

Incremental cardiopulmonary exercise tests

Two incremental protocols were used for determination of VT_1 , VT_2 , and $\text{VO}_{2\text{max}}$. The subjects were positioned on the treadmill (Inbramed, TK10200, Porto Alegre, Brazil) and initially walked $2.0 \text{ km}\cdot\text{h}^{-1}$ and 1% grade for 2 min. The speed protocol then increased to $5.5 \text{ km}\cdot\text{h}^{-1}$ and 1% of grade and increments of 0.1 to $0.3 \text{ km}\cdot\text{h}^{-1}$ were added every 15s (Figure 1A), with a constant grade (Figure 1C). If the maximal speed of the treadmill ($16 \text{ km}/\text{h}$) was attained, exercise intensity was further increased by grade increments of 0.5% per 30s. The grade protocol started at $5.5 \text{ km}\cdot\text{h}^{-1}$ and 1% of grade, with increments of $0.1 \text{ km}\cdot\text{h}^{-1}$ every 45s (Figure 1B) and 1% increases in grade every 30s (Figure 1D). Subjects exercised until volitional fatigue. During recovery from the incremental tests, subjects walked on the treadmill at $2 \text{ km}\cdot\text{h}^{-1}$ for 7 min. Fingertip blood samples were collected at 1, 3, 5, and 7 min for the determination of maximal blood lactate during recovery.

Cardiorespiratory variables

Heart Rate (HR) was determinate based on the R-R intervals from a twelve-lead electrocardiogram



(Micromed-Biotecnologia, Brasília, Brazil). Perceived exertion using the 0 to 10 Borg scale²⁵ was obtained every 2 min. Gas exchange variables were measured breath-by-breath by a validated system (Metalyzer 3B, CPET System, Cortex, Leipzig, Germany) and expressed in 20s intervals.²⁶ $\dot{V}O_2$ max was defined as the highest value measured for a period of 20s during the CPET. VT_1 and VT_2 were determined by visual inspection. VT_1 was identified as the $\dot{V}O_2$ or HR immediately before a systematic increase in the ventilatory equivalent for oxygen (minute ventilation [VE] / $\dot{V}O_2$), without an increase in the ventilatory equivalent for carbon dioxide (VE / carbon dioxide output [$\dot{V}E_{CO_2}$]).^{3,27} The V-slope

method was also used to confirm the VT_1 . VT_2 was identified as the point immediately before a systematic increase in VE/VE_{CO_2} , usually at the same time that the end-tidal CO_2 decreased systematically.³ All ventilatory thresholds and $\dot{V}O_2$ max evaluations were determined by the same experienced researcher, who was blinded to the protocols.

Exercise prescription

The exercise intensity during the submaximal exercise sessions was based on the HR corresponding to the mean point between VT_1 and VT_2 , obtained from the speed and grade protocols. During submaximal exercise sessions,

the subjects underwent 10 min of walking-running in order to reach the target HR, followed by 30 min running at target HR. The treadmill was maintained at a constant level during the submaximal exercise sessions and speed was adjusted to maintain a stable HR. Rather than applying a constant workload, we chose to maintain a stable HR because the individuals exercised at intensities above the VT₁, where the steady state is not established with a constant work rate.^{13,28} Moreover, the target HR is frequently used to monitor aerobic training exercise sessions in practice.⁴ During the submaximal exercise sessions, HR and gas exchange responses were continuously monitored as described above. Perceived exertion and blood lactate samples were obtained at rest and every 10 min.

Blood lactate analysis

Twenty-five μL fingertip blood samples were mixed with 50 μL of 1% sodium fluoride. This solution was then frozen for later analysis of blood lactate concentration using a dedicated analyzer (YSI 1500-L Sport, Yellow Springs, Ohio, USA).

Statistical analysis

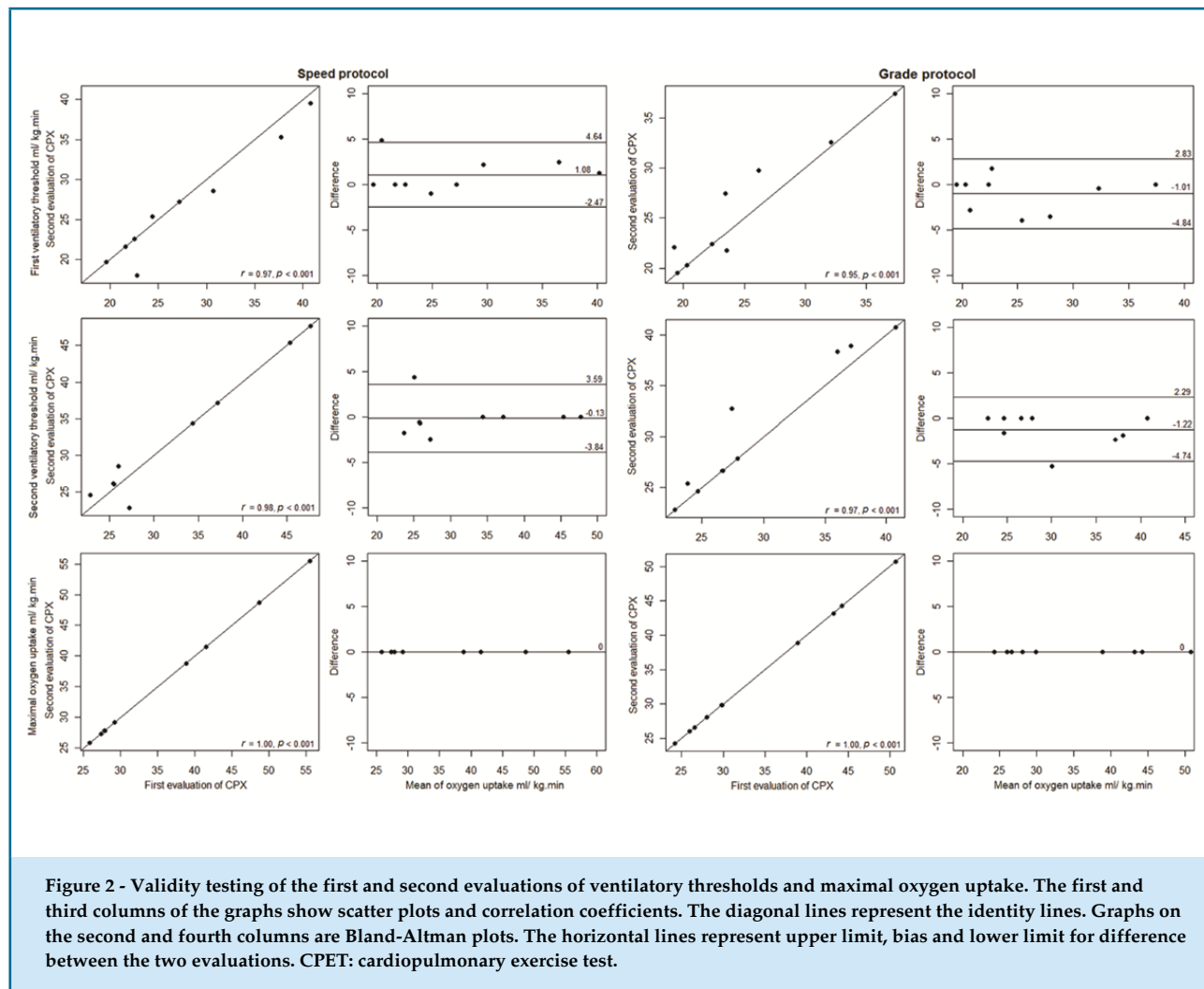
Based on a previous study,²⁹ a minimum sample size was estimated to be 7 subjects, using a power of 90% and an alpha of 0.05 to detect a 10% difference (16 bpm) in the prescribed HR between protocols. Two subjects were added to the sample to account for dropouts. We used the Kolmogorov-Smirnov test to assess the normality of variables. Descriptive data are presented as mean (M) and standard deviations (SD) and 95% confidence interval (95% CI). To evaluate intra-observer reproducibility in the detection of VT₁, VT₂, and VO₂max, gas exchange curves of all tests were reviewed by the same blinded investigator twice within a one-week interval. Paired t tests, Pearson's correlation coefficients, and Bland-Altman analyses³⁰ were used to assess intra-observer reproducibility. The responses to incremental and submaximal exercise tests were compared using paired t tests for two means and by generalized estimating equations for three or more means. When appropriate, multiple comparisons were evaluated using Bonferroni correction. The calculations for sample size, planning for randomization and Bland-Altman analyses were performed using R 3.0 (Free Software Foundation's GNU Project), and all other analyses were performed using SPSS 21.0 software (IBM, New York, USA).

Results

All subjects completed the incremental exercise tests and the exercise sessions without complications. For the intra-observer reproducibility analysis, there were no significant differences in VO₂ (ml.kg⁻¹.min⁻¹) between the two evaluations in terms of detection of VT₁ ("speed": 27.5 \pm 7.4 [95% CI = 21.8; 33.2] vs 26.4 \pm 7.2 [95% CI = 20.9; 31.9], *p* = 0.11; "grade": 24.9 \pm 6.1 [95% CI = 20.2; 29.6] vs 25.9 \pm 6.2 [95% CI = 21.1; 30.7], *p* = 0.16); VT₂ ("speed": 32.4 \pm 9.2 [95% CI = 25.3; 39.5] vs 32.5 \pm 9.2 [95% CI = 25.4; 39.6], *p* = 0.85; "grade": 29.7 \pm 6.5 [95% CI = 24.6; 34.7] vs 30.9 \pm 6.9 [95% CI = 25.6; 36.2], *p* = 0.08), and VO₂max ("speed": 35.8 \pm 10.8 [95% CI = 27.5; 44.2] vs 35.8 \pm 10.8 [95% CI = 27.2; 44.2], *p* = 0.99; "grade": 34.7 \pm 9.7 [95% CI = 27.2; 42.1] vs 34.7 \pm 9.8 [95% CI = 27.2; 42.1], *p* = 0.99). Intra-observer agreement results are presented in Figure 2. The two protocols exhibited strong correlation coefficients between the first and second evaluations, varying from 0.95 to 1.00 (1st and 3rd columns of Figure 2). Likewise, Bland-Altman plots demonstrated values within the acceptable limits of agreement between the first and second evaluations (2nd and 4th columns of Figure 2).

Table 1 shows the incremental exercise test results performed according to the speed and grade protocol. Resting HR and blood lactate were similar between the protocols. At peak exercise, HR was higher with the speed protocol, while no differences were observed between VO₂max, VCO₂max, and VEmax. Peak respiratory exchange ratio was lower with the speed protocol, as well as perceived leg exertion. Maximal blood lactate concentrations and time to maximal blood lactate concentration during recovery were similar with the two protocols.

Figure 3 shows VO₂ and HR responses to incremental exercise according to VT₁, VT₂, the mean point between VT₁ and VT₂, and VO₂max. VO₂ at these 4 intensities was higher with the speed protocol (Figure 3A). When expressed as a percentage of VO₂max, these differences were also statistically significant (Intensity: *P* < 0.01; Protocol: *P* = 0.01; Interaction: *P* = 0.18). The "speed" protocol resulted in higher HR (bpm) for the VT₁ (153 \pm 14 [95% CI = 146; 168] vs 144 \pm 8 [95% CI = 137; 150], *p* < 0.01), the VT₂ (176 \pm 7 [95% CI = 171; 182] vs 165 \pm 8 [95% CI = 159; 171], *p* < 0.01), the mean point between VT₁ and VT₂ (169 \pm 9 [95% CI = 162; 176] vs 156 \pm 8 [95% CI = 150; 162], *p* < 0.01), and peak exercise (189 \pm 8 [95% CI =



183; 195] vs 183 ± 7 [95% CI = 178; 188], $p < 0.01$) (Figure 3B). The responses were also significantly different when HR was analyzed as a percentage of the peak (Intensity: $p < 0.01$; Protocol: $p < 0.01$; Interaction: $p = 0.01$).

The submaximal exercise sessions were analyzed from 10 to 40 min, corresponding to the steady-state phase of exercise (Figure 4). Similarly to the comparison of protocols, subjects exhibited stable HR responses (Figure 4A), with higher levels observed during the session based on the speed protocol. Blood lactate concentrations (Figure 4B) were stable after 20 min, with higher concentrations observed during the speed protocol. To maintain a stable HR, speed was progressively reduced (Figure 4C), resulting in a reduction of VO_2 (Figure 4D). VE/VO_2 increased progressively (Figure 4E), but there were no significant differences between protocols. The respiratory exchange ratio decreased progressively (Figure 4F), with significant differences between the

protocols. Perceived rates of respiratory (Figure 4G) and leg (Figure 4H) exertion were significantly higher during the sessions based on the speed protocol.

Discussion

The major finding of the present study was that a treadmill protocol based mainly on speed increments resulted in higher VO_2 and HR corresponding to the VT_1 and VT_2 when compared to a treadmill protocol based mainly on grade increments. Moreover, the choice of the protocol had a significant impact on exercise prescription based on ventilatory thresholds. To our knowledge, this is the first report describing the impact of the type of increment during CPET performed on the treadmill on aerobic exercise prescriptions.

Previous studies have shown that, when the cycle ergometer is used for the detection of ventilatory

Table 1 - Ergometric data, cardiorespiratory, and metabolic results at rest and incremental exercise test with the speed and grade protocol

	Speed (n = 9) M ± SD (95% CI)	Grade (n = 9) M ± SD (95% CI)
Rest		
Heart rate (beats.min ⁻¹)	72 ± 12 (65; 79)	73 ± 12 (66; 81)
Blood lactate (mmol.L ⁻¹)	1.79 ± 0.62 (1.41; 2.17)	1.69 ± 0.59 (1.33; 2.06)
Peak exercise		
Time (s)	694 ± 206 (574; 821)	568 ± 151 (483; 662)*
Speed (km.h ⁻¹)	13.5 ± 2.5 (12.0; 14.9)	6.2 ± 0.3 (6.0; 6.4)*
Grade (%)	2.6 ± 2.6 (1.2; 4.3)	19.7 ± 4.9 (16.8; 22.7)*
Heart rate (beats.min ⁻¹)	189 ± 6 (184; 193)	183 ± 7 (179; 187)*
Oxygen uptake (ml.kg ⁻¹ .min ⁻¹)	35.8 ± 10.8 (29.7; 43.2)	34.7 ± 9.7 (28.9; 41.0)
Carbon dioxide output (L.min ⁻¹)	2.69 ± 1.0 (2.05; 3.28)	2.88 ± 1.16 (2.16; 3.54)
Minute ventilation (L.min ⁻¹)	102 ± 33 (81; 122)	106 ± 34 (84; 127)
Respiratory exchange ratio	1.14 ± 0.11 (1.06; 1.20)	1.25 ± 0.11 (1.17; 1.31)
Perceived exertion		
Respiratory	9 ± 2 (8; 10)	9 ± 1 (8; 10)
Legs	8 ± 2 (7; 10)	9 ± 1 (9; 10)*
Maximal blood lactate during recovery		
Blood lactate (mmol.L ⁻¹)	9.07 ± 2.29 (7.30; 10.83)	9.95 ± 2.25 (8.21; 11.68)
Time to maximal (min)	2 ± 2 (0.5; 3)	3 ± 2 (1; 5)

*M: mean; SD: standard deviation; 95%CI: 95% confidence interval. * p < 0.01.*

thresholds, the results are independent of the rate of increment in power output.^{9,31,32} The detection of VT₁ is also not affected by the rate of increment in exercise intensity on the treadmill.¹⁴ Despite the fact that the treadmill is the ergometer of choice in many clinical settings, no study has previously evaluated the impact of changing grade versus speed on the detection of ventilatory thresholds using the treadmill. Kinderman et al.,¹⁵ evaluated the influence of different incremental treadmill protocols on the detection of the 4 mmol.L⁻¹ lactate threshold. In agreement with what had been shown for the cycle ergometer,⁹ when fixed, absolute blood lactate concentrations are used to detect thresholds, and the results were dependent on the protocol used. In the present study, VO₂ values at the ventilatory thresholds were ~7% higher on the speed-based protocol when compared to the grade-based

protocol. Likewise, HR at the ventilatory thresholds was ~8% higher on the speed-based protocol when compared to the grade-based protocol. The mechanisms by which a speed-based protocol results in higher ventilatory thresholds when compared to a grade-based protocol are not readily apparent from our data. Based on the findings of Kelsey & Duffin,¹⁹ in which greater ventilatory responses to speed than grade increments were observed on the treadmill for the same VO₂, one would expect lower ventilatory thresholds with the speed protocol, assuming that greater limb movement frequency would be responsible for our findings. An additional potential explanation for the lower ventilatory thresholds for the grade-based protocol is activation of a larger muscle mass with increments in grade.²³ During uphill (+10%) running, the volume of activated limb muscles increases from 67% to 73%,

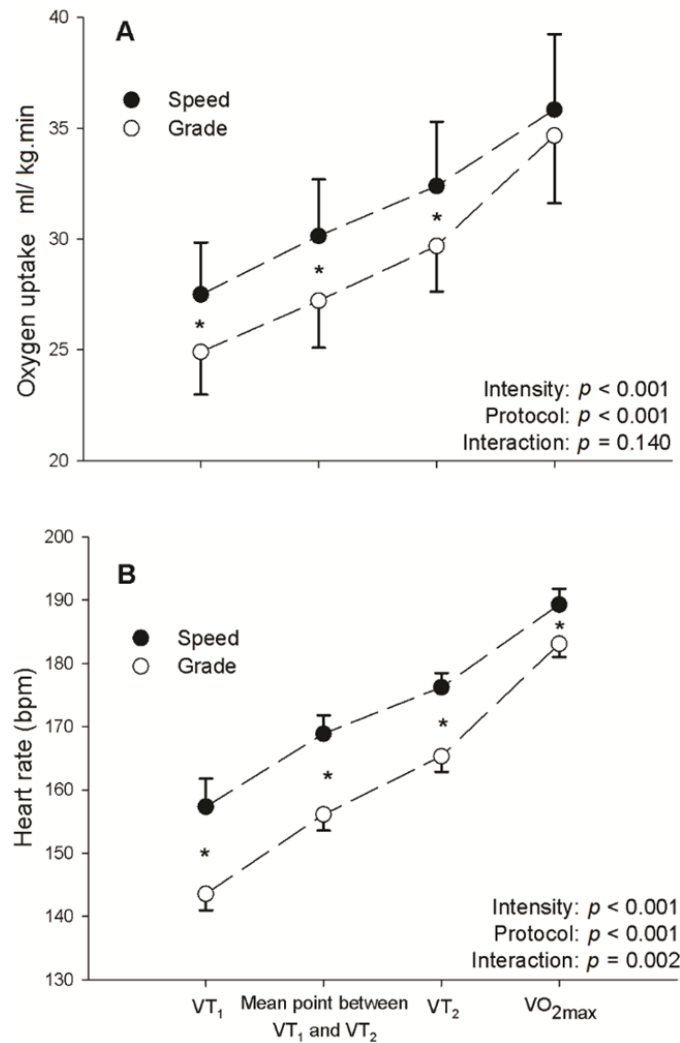


Figure 3 - Oxygen consumption and heart rate responses at four points during the maximal exercise tests with the speed and grade protocols. Data are expressed as mean \pm SE. VT₁: first ventilatory threshold; VT₂: second ventilatory threshold. * $p < 0.01$ between protocols.

and this is associated with greater oxygen deficit.²¹ Moreover, uphill running is associated with greater glycogen depletion in the lower extremities.³³ Therefore, the grade-based protocol used in the present study probably resulted in the activation of a larger muscle mass, greater glycogen utilization, and earlier blood lactate accumulation, resulting in a lower VO_2 at the ventilatory thresholds.

Some investigators have suggested that the prescription of exercise intensities for aerobic training using ventilatory (or blood lactate) thresholds as the

reference is more physiologically sound than using a percentage of VO_2 max or a percentage of maximal HR.^{4,6,34} Despite the fact that there are few data from controlled studies to support this strategy,³⁵ the concept that individuals with different ventilatory thresholds may exhibit different metabolic and cardiorespiratory responses to exercise at a given percentage of VO_2 max is well established.^{4,6,13,34} Therefore, we compared metabolic and cardiorespiratory responses during exercise sessions with the intensities determined on CPET based on either speed or grade increments. As is commonly done in practice, exercise intensity was

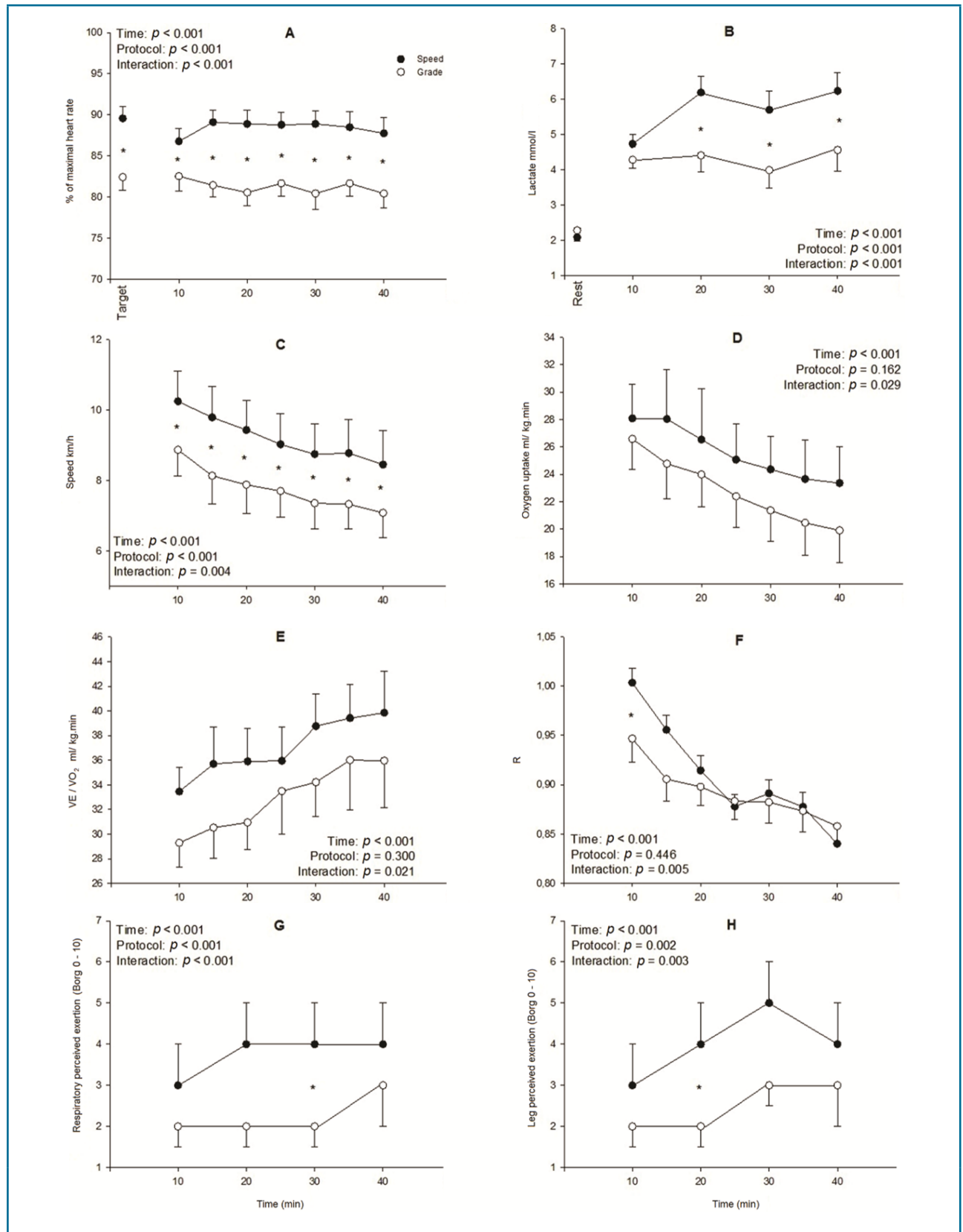


Figure 4 - Ventilatory and metabolic results from the prescribed submaximal exercise tests according to the speed and grade protocols. Darkened circles: exercise prescription based on the speed protocol; open circles: exercise prescription based on the grade protocol. All p values were obtained from generalized estimating equations. VE/VO_2 : ventilatory equivalent for oxygen. * $p < 0.05$ between protocols.

adjusted according to the HR corresponding to the mean point between VT_1 and VT_2 . Our data show that the choice of protocol has a significant impact on the exercise intensity prescribed for aerobic training based on the determination of ventilatory thresholds. The speed-based protocol resulted in a higher HR, blood lactate, speed, and perceived exertion during the exercise sessions. The size of this difference ($\sim 8\%$ for HR and ~ 2 mmol.L⁻¹ for blood lactate) is substantial. If, for instance, the exercise prescription were to be set at the HR corresponding to VT_2 , the steady state blood lactate concentration would be reached using a grade-based protocol, but blood lactate would likely accumulate if a speed-based protocol was used.¹³

Our study has several limitations. Ventilatory thresholds were visually determined by one experienced investigator (JPR) blinded to the identity of the subjects and the utilized protocol. Despite the fact that we did not evaluate the inter-observer agreement for the detection of thresholds, the intra-observer agreement was appropriate,^{11,27} as demonstrated by similar mean values, high correlation coefficients, and Bland-Altman analyses within acceptable limits. Moreover, the standard criteria used in clinical practice, including ventilatory equivalents, V-slope, and the end-tidal CO₂, were applied.^{3,36} With this approach, the reproducibility for the detection of the ventilatory threshold was in agreement with previous studies.^{31,36-38} Furthermore, to avoid the walking-running transition, which affects the linearity of VO₂ response, both protocols began at 5.5 km/h, a speed at which all subjects were jogging. Perhaps, other faster transition speeds might produce different results, which in fact may be the subject of a future experiment. Therefore, our findings cannot be extrapolated to protocols in which individuals do not run. Finally, our findings are limited to healthy young adults, and therefore may not be applicable to elderly individuals, children or those with pathological conditions.

Conclusion

A speed-based protocol results in higher ventilatory thresholds when compared to a grade-based protocol during CPET performed on a treadmill. These findings have a significant impact on cardiorespiratory and

metabolic responses to prescribed exercise intensity in healthy subjects. Due to fact that exercise prescription based on CPET often requires a high degree of confidence and safety, it is necessary to keep in mind that the same protocol must be utilized when the subject is re-tested during clinical practice. Finally, the speed-based protocol was more convenient because it was more applicable for exercise prescription.

Acknowledgements

This work was supported by the *Hospital de Clínicas de Porto Alegre* Fund for the Incentive of Research (FIPE/HCPA) from Porto Alegre, Brazil; the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES), Brasília, Brazil; and the Brazilian Research Council (CNPq) Brasília, Brazil.

Author contributions

Conception and design of the research: Belli KC. Acquisition of data: Belli KC, Silva PF. Analysis and interpretation of the data: Belli KC, Silva PF, Franzoni LT, Myers J, Stein R. Statistical analysis: Belli KC, Franzoni LT. Writing of the manuscript: Belli KC, Myers J, Stein R. Critical revision of the manuscript for intellectual content: Belli KC, Franzoni LT, Myers J, Stein R.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Sources of Funding

There were no external funding sources for this study.

Study Association

This article is part of the thesis of doctoral submitted by Karlyse C. Belli, from *Universidade Federal do Rio Grande do Sul*.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

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