Influence of Different Treadmill Inclinations on $\dot{V}O_2$max and Ventilatory Thresholds During Maximal Ramp Protocols

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Abstract

Silva, SC, Monteiro, WD, Cunha, FA, and Farinatti, P. Influence of different treadmill inclinations on $\dot{V}O_2$max and ventilatory thresholds during maximal ramp protocols. *J Strength Cond Res* 35(1): 233–239, 2021—Ramp protocols for cardiopulmonary exercise testing (CPET) lack precise recommendations, including optimal treadmill inclination. This study investigated the impact of treadmill grades applied in ramp CPETs on maximal oxygen uptake ($\dot{V}O_2$max), ventilatory thresholds (VT1/VT2), and $\dot{V}O_2$ vs. workload relationship. Twenty-one healthy men (age 33 $\pm$ 8 years; height 176.6 $\pm$ 5.8 cm; body mass 80.4 $\pm$ 8.7 kg; and $\dot{V}O_2$max 44.9 $\pm$ 5.7 ml·kg^{-1}·min^{-1}) and 12 women (age 29 $\pm$ 7 years; height 163.3 $\pm$ 6.7 cm; body mass 56.6 $\pm$ 6.3 kg; and $\dot{V}O_2$max 39.4 $\pm$ 4.9 ml·kg^{-1}·min^{-1}) underwent ramp CPETs with similar speed increments and different treadmill grades: CPET0%, CPET2%, CPET3.5%, and CPET5.5%. The $\dot{V}O_2$max was similar across protocols (42.8–43.2 ml·kg^{-1}·min^{-1}, $p = 0.76$), albeit duration of CPETs shortened when treadmill inclination increased (CPET0% 12.7 minutes; CPET2% 9.1 minutes; CPET3.5% 8.0 minutes; and CPET5.5% 6.6 minutes; $p < 0.01$). The %$\dot{V}O_2$max corresponding to VT1 was slightly lower in CPET0% (63.6%) and higher in CPET5.5% (75.8%) vs. CPET2% (67.8%) and CPET3.5% (69.5%; $p < 0.05$), whereas VT2 was not affected by treadmill inclination (95.1–95.8% $\dot{V}O_2$max; $p > 0.05$). $\dot{V}O_2$max and ventilatory thresholds were similar in CPETs performed with different treadmill inclinations and similar initial/final speeds. However, linear regressions between workload and $\dot{V}O_2$ were closer to the identity line in CPETs performed with smaller (CPET0% and CPET2%) than with greater (CPET3.5% and CPET5.5%) inclinations. These data suggest that in healthy young adults, ramp CPETs performed with inclinations of 0–2% degree should be preferred over protocols with greater inclinations.

Key Words aerobic exercise, cardiopulmonary exercise testing, cardiorespiratory physiology, health

Introduction

The term "ramp protocol" refers to cardiopulmonary exercise testing (CPET) performed with small and continuous increases in work rate, typically resulting in total test duration of 8–12 minutes (6,7,23). Whipp et al. (26) were probably the first to investigate the cardiorespiratory responses during ramp CPETs. However, this modality of test gained popularity after data were published by Myers et al. (22,23) showing that linearity between oxygen uptake ($\dot{V}O_2$) and work rate improved along ramp vs. traditional tests performed with larger work increments and longer stage durations (e.g., Bruce and Balke protocols). In general, ramp protocols are acknowledged to limit volitional fatigue in comparison with multistage CPETs by lowering peripheral fatigue and therefore allowing the individual to achieve greater peak $\dot{V}O_2$ (5,6,21).

Despite these widely accepted advantages, standardized criteria to guide the application of ramp CPETs remain scarce in regards to several aspects. A previous review (7) highlighted the following features: (a) The definition of final speed based on exercise capacity estimated from nonexercise models; (b) strategies to determine the initial speed of testing; and (c) in the case of walking/running protocols, the influence of treadmill inclination on cardiorespiratory responses. Our group addressed the first 2 issues: da Silva et al. (6) compared in 117 healthy individuals 3 often applied nonexercise models to estimate maximal exercise capacity, as criteria to determine final and initial speeds in treadmill ramp protocols (Veterans Specific Activity Questionnaire–VSAQ (20); Rating of Perceived Capacity–RPC (28); and Questionnaire of Cardiorespiratory Fitness–CRF (17)). The

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maximal $\dot{V}O_2$ ($\dot{V}O_2$max) attained when final speed was determined using CRF was higher and more reproducible vs. RPC and VSAQ. As for the initial workload, $\dot{V}O_2$max was unaffected when tests began at speeds corresponding to 50–60% $\dot{V}O_2$max, either estimated or measured. However, the $\dot{V}O_2$ vs. workload regression in tests beginning at 50% $\dot{V}O_2$max estimated by CRF exhibited closer relationship to the identity line, therefore better reflecting physiological responses along submaximal exercise.

The treadmill inclination is a crucial feature of ramp CPETs, affecting peripheral fatigue and test duration. The analysis of some studies with ramp protocols revealed that the range of usually applied inclinations is about 25% degree (1,22–24), which represents 2.5% of slope per min within a test lasting 10 minutes. In practical terms, this percentage of inclination corresponds to $1.4° \cdot min^{-1}$, leading to a total inclination of 14°. Based on the premise that the rate of workload increasing in ramp protocols ought to be balanced to avoid early peripheral fatigue and provide easy interpretation of physiological data, lower combinations of slopes/velocities should be ideally applied during the test. Nonetheless, we could not find studies specifically investigating the potential influence of treadmill grades on cardiorespiratory responses at submaximal and maximal intensities during ramp CPETs.

Given this gap in the literature, this study compared the $\dot{V}O_2$max and ventilatory thresholds obtained in ramp CPETs performed with similar rate of speed increment, but different treadmill inclinations. We hypothesized that both maximal and submaximal respiratory responses would be affected by treadmill inclination, due to variations in peripheral fatigue during CPETs.

Methods

Experimental Approach to the Problem

Each subject visited the laboratory 4 times and tests were applied interspersed with 48–72-hour intervals. Subjects were recommended to abstain from alcohol, caffeine, ergogenic beverages, and exercise in the 24 hours before CPET sessions. On the first visit, anthropometric measurements were taken and a reference ramp CPET was performed with treadmill grade set at 0% (CPET0%). On second, third, and fourth visits, subjects performed maximal CPETs with treadmill grades set at 2% (CPET2%), 3.5% (CPET3.5%), and 5.5% (CPET5.5%), respectively, in a randomized counterbalanced order. Figure 1 illustrates the experimental design, including procedures for determining maximal exercise capacity from CRF and calculation of work rate increments by means of American College of Sports Medicine running equation, as described elsewhere (6).

The CRF was used to predict subjects' maximum cardiorespiratory capacity to estimate initial and final speeds in CPET0%. The CRF was originally validated to predict the aerobic capacity of healthy individuals of both sexes aged 19–79 years (17). The adoption of this specific questionnaire was due to data from a previous study from our group, which compared 3 different nonexercise models to estimate $\dot{V}O_2$max. We have demonstrated that the CRF was the best option to determine initial and final speeds within ramp CPETs based on estimated $\dot{V}O_2$max (6). Data from this study also justify why the initial speed of CRF was set at 50% of predicted $\dot{V}O_2$max. Although the measured $\dot{V}O_2$max was not affected by initial speeds applied to ramp CPETs, velocities corresponding to intensities higher than 50% $\dot{V}O_2$max produced poorer submaximal relationships between workload and $\dot{V}O_2$.

The choice of treadmill inclinations must also be justified. Because our intention was to investigate the influence of inclination in tests designed to determine the maximum exercise capacity, it was important to minimize factors that could compromise this analysis. The biomechanics of running might represent a problem if excessive inclinations are applied. Accordingly, previous studies have shown that the rise in velocity associated with high percent inclinations may require drastic increases in hip, knee, and ankle flexion angles, therefore predisposing to early fatigue. These unfavorable biomechanical modifications have been reported at speeds around 10–11 $km \cdot h^{-1}$ and inclinations of approximately 5.0–5.5% degree (12,25). For this reason, the highest percent inclination presently applied was of 5.5%. In regards to the inclinations of 2.0% and 3.5%, the tangent arc of these slope percentages corresponded to differences between protocols of approximately 1 degree in actual inclination (2% = 1.1°, 3.5% = 2.0°, 5.5% = 3.1°).

Subjects

After advertisement by internet, 21 men (mean ± *SD*, age 33 ± 8 years [range 22 to 46 years]; height 176.6 ± 5.8 cm; body mass 80.4 ± 8.7 kg; body fat 12.4 ± 6.4%; and $\dot{V}O_2$max in CPET0% 44.9 ± 5.7 $ml \cdot kg^{-1} \cdot min^{-1}$) and 12 women (age 29 ± 7 years [range 22 to 44 years]; height 163.3 ± 6.7 cm; body mass 56.6 ± 6.3 kg; body fat 19.1 ± 4.4%; and $\dot{V}O_2$max in CPET0% 39.4 ± 4.9 $ml \cdot kg^{-1} \cdot min^{-1}$) were recruited for the study. Exclusion criteria included: (a) use of cardiovascular or metabolic medications; (b) smoking, or use of ergogenic substances that could affect exercise performance; and (c) cardiovascular, respiratory, bone, muscle, or joint problems that could limit physical exercise. All subjects provided written informed consent before participation and the experiment gained approval of the ethics review board of the University of Rio de Janeiro State (process 3082/2011).

Procedures

Cardiopulmonary Exercise Testing. The reference test (CPET0%) was performed with treadmill inclination set at 0% and individualized increase in work rate to elicit subjects' limit of tolerance within 10 minutes. Final and initial speeds were determined using American College of Sports Medicine equations for treadmill running, considering 100 and 50% $\dot{V}O_2$max estimated by the CRF questionnaire, respectively (6). Subsequently, CPETs were performed with 3 percent

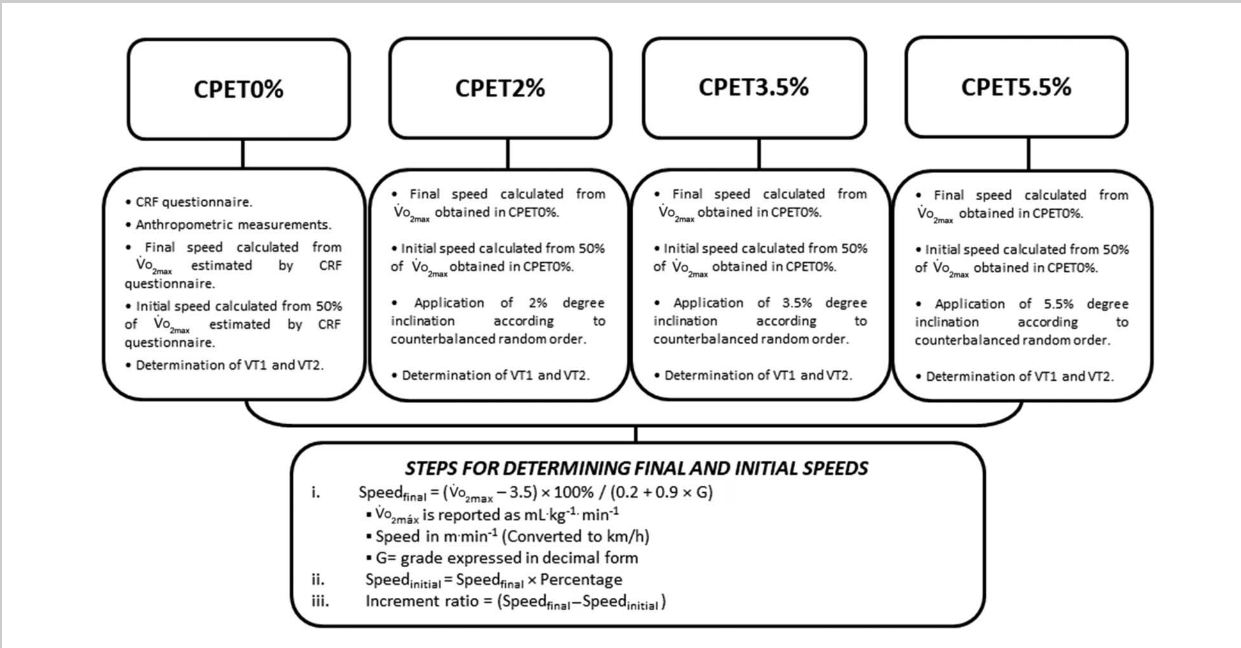

Figure 1. Study design. Cardiopulmonary exercise testing performed with different treadmill inclinations ($n = 33$).

grades: 2, 3.5, and 5.5%. In these tests, initial and final speeds corresponded respectively to 100 and 50% $\dot{V}O_2$max as determined in CPET0%, with rate of increment calculated for an estimated duration of 10 minutes. It is normal that the rate of load increment within ramp CPETs vary from person to person because it is protocol-dependent. However, the variation for each individual was the same irrespective of slope, so that differences in the rate of increment along the test should be due to treadmill slope and not velocity.

Tests were performed using a Super-ATL treadmill (Inbramed, Florianopolis, SC, Brazil) and $\dot{V}O_2$ was averaged and recorded every 30 seconds. The 30-second time average provided a good compromise between removing noise from $\dot{V}O_2$ data while maintaining the underlying trend (19). Gas exchange was assessed by means of a VO2000 analyzer (Medical Graphics, St. Louis, MO), which was calibrated with a certified standard mixture of oxygen (17.01%) and carbon dioxide (5.00%) balanced with nitrogen. Flows and volumes of pneumotachograph were calibrated with a 3 L syringe (Hans Rudolph, Kansas, MO). Heart rate was continuously assessed using a Polar S-810 device (Polar, Kempele, Finland). Mean ambient temperature and relative humidity during CPETs were of 22.0 ± 2.0° C (range 18–23) and 62.9 ± 4.5% (range 50–75%), respectively.

The CPETs were considered as maximal in the presence of at least 3 of 4 criteria (13): (a) maximum voluntary exhaustion as reflected by score 10 on Borg CR-10 scale; (b) ≥95% predicted HRmax (220–age) or presence of HR plateau (Δ HR between 2 consecutive work rates $\leq$4 $b \cdot min^{-1}$); (c) presence of $\dot{V}O_2$ plateau (Δ $\dot{V}O_2$ between 2 consecutive work rates <2.1 $ml \cdot kg^{-1} \cdot min^{-1}$); and (d) respiratory exchange ratio >1.15. Subjects were verbally encouraged to achieve maximal effort. Holding onto the side or front rails of the treadmill was not permitted.

Determination of Ventilatory Thresholds. Ventilatory thresholds were determined from gas exchange data, particularly ventilatory equivalents of $\dot{V}O_2$ (VE/$\dot{V}O_2$) and carbon dioxide (VE/$\dot{V}CO_2$), and expired fractions of O_2 ($PETO_2$) and CO_2 ($PETCO_2$). The first ventilatory threshold (VT1) referred to the point at which VE/$\dot{V}O_2$ increased concomitantly to $PETO_2$, without proportional changes in VE/$\dot{V}CO_2$ and $PETCO_2$. The second ventilatory threshold (VT2) corresponded to the point at which a simultaneous increase in VE/$\dot{V}O_2$, VE/$\dot{V}CO_2$, and $PETO_2$ occurred, with a decrease in $PETCO_2$ (3). VT1 and VT2 were determined in a double-blind fashion by 2 experienced and independent evaluators (S.C.S. and W.D.M.), with no previous knowledge of treadmill inclination to which data concerned. The average of VT1 and VT2 obtained by the 2 evaluators was recorded. However, values should not differ more than 10% between evaluators. In this case, a tertio intervened (F.A.C.) and the average of 2 closest values was retained as result. Agreement between evaluators for VT1 and VT2 was calculated by means of intraclass correlation (VT1: range 0.91–0.95; VT2; range 0.93–0.97; $p < 0.01$).

Statistical Analyses

Data normality was confirmed using the Kolmogorov-Smirnov test and therefore, data are presented as mean values ± *SD*s. Potential differences in $\dot{V}O_2$max due to

Table 1. Data of cardiopulmonary exercise tests (CPETs) performed according ramp protocols with similar rates of speed increment and different inclinations in young men and women ($n = 33$).

	Treadmill inclination				
	CPET0%	CPET2%	CPET3.5%	CPET5.5%	p
Total CPET duration (min)	12.7 ± 1.8*	9.1 ± 0.8†	8.0 ± 0.8†	6.6 ± 0.8	*<0.0001; †<0.01
Time of VT1 (min)	4.7 ± 1.7*	2.7 ± 1.0	2.2 ± 0.7	2.2 ± 0.8	<0.0001
Time of VT2 (min)	11 ± 1.9*	8.0 ± 0.8*	6.9 ± 0.9*	5.6 ± 0.9*	<0.0001
HRpeak (b·min^{-1})	185 ± 10	184 ± 10	185 ± 9	183 ± 9	0.30
$\dot{V}O_2$max (L)	3.1 ± 0.8	3.1 ± 0.7	3.1 ± 0.8	3.1 ± 0.8	0.78
$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})	42.9 ± 6.0	43.2 ± 5.9	42.8 ± 5.9	42.8 ± 5.7	0.76
Speed of VT1 (km·h^{-1})	9.3 ± 1.4	9.4 ± 1.2	9.1 ± 1.1	9.1 ± 1.1	0.53
$\dot{V}O_2$ of VT1 (ml·kg^{-1}·min^{-1})	26.9 ± 3.9*	29.2 ± 4.2†	29.6 ± 5.7	32.3 ± 5.0	*<0.05; †<0.001
$\dot{V}O_2$ of VT1 (% $\dot{V}O_2$max)	63.6 ± 9.7*	67.8 ± 7.6†	69.4 ± 6.5†	75.8 ± 9.0	*<0.05; †<0.001
Speed of VT2 (km·h^{-1})	14.2 ± 1.8*	13.2 ± 1.7†	12.5 ± 1.8†	11.5 ± 1.6	*<0.05; †<0.05
$\dot{V}O_2$ of VT2 (ml·kg^{-1}·min^{-1})	40.9 ± 5.8	41.5 ± 5.8	41.0 ± 5.7	40.9 ± 5.7	0.92
$\dot{V}O_2$ of VT2 (% $\dot{V}O_2$max)	95.1 ± 2.8	95.8 ± 2.8	95.8 ± 2.5	95.6 ± 2.8	0.59
Borg score	10 ± 1	10 ± 1	10 ± 1	10 ± 1	0.15

*Significantly different from all other CPETs.
†Significantly different from CPET5.5%.

treadmill inclinations were checked using repeated-measures analysis of variance followed by Fisher LSD post hoc tests, in the event of significant F ratios. Data obtained at each 30 seconds of CPETs were used to calculate individual regression curves between workload and $\dot{V}O_2$. R-squared values (r^2) and standard errors of estimate (SEE) were calculated for regression curves in all CPETs to establish which inclination provided the best linear relationship along submaximal intensities. In addition, t-tests for paired samples were used to test whether intercepts and slopes of those regression models significantly differed from the identity line (slope = 1 and intercept = 0), as described elsewhere (5,6). Statistical significance was set at $p \leq 0.05$ and all calculations were performed using the software SPSS 19.0 (SPSS, Inc., IBM Company, IL).

Results

Mean initial speeds corresponding to 50% $\dot{V}O_2$max and individual rates of speed increment applied in CPETs performed with treadmill inclinations (e.g., CPET2%, CPET3.5%, and CPET5.5%) were of 7.0 ± 0.7 km·h^{-1} and 0.66 ± 0.10 m·min^{-1} for females (range 5.6–7.7 km·h^{-1} and 0.52–0.83 m·min^{-1}) and of 7.8 ± 0.5 km·h^{-1} and 0.75 ± 0.15 m·min^{-1} for males (range 7.2–8.9 km·h^{-1} and 0.53–0.99 m·min^{-1}), respectively.

Table 1 presents total duration of CPETs, maximal heart rate (HRmax), $\dot{V}O_2$max, VT1, and VT2 (with corresponding speeds and $\dot{V}O_2$). Although test durations were shorter when treadmill inclination increased, no difference was detected for $\dot{V}O_2$max or HRmax. Interestingly, albeit speeds at VT1

Table 2. Mean values of intercepts, slopes, determination coefficients (r^2), and standard errors of estimate (SEE) obtained in the individual regression models for ramp treadmill cardiopulmonary exercise tests (CPETs) performed with different inclinations.

	Y Intercept	Slope	r^2	SEE (ml·kg^{-1}·min^{-1})
$\dot{V}O_2$ vs. workload (CPET0%)	−2.718 ± 3.552*	0.98 ± 0.009†	0.95	1.80
$\dot{V}O_2$ vs. workload (CPET2%)	−8.930 ± 5.412*	0.95 ± 0.021†	0.91	2.29
$\dot{V}O_2$ vs. workload (CPET3.5%)	−11.368 ± 5.799*	0.93 ± 0.027†	0.87	2.79
$\dot{V}O_2$ vs. workload (CPET5.5%)	−18.546 ± 9.271*	0.91 ± 0.032†	0.83	3.22

*Intercept significantly different of 0 ($p < 0.0001$).
†Slope significantly different of 1 ($p < 0.0001$); workload (km·h^{-1}); $\dot{V}O_2$ = oxygen uptake.

have been similar in CPETs performed with different inclinations, the corresponding $\dot{V}O_2$ (absolute and relative) increased in greater inclinations. By contrast, $\dot{V}O_2$ associated with VT2 (absolute and relative) did not differ between protocols, but the speed corresponding to this intensity lowered when inclination increased. Finally, no difference between protocols was found for perceived exertion at the end of CPETs.

Table 2 shows data of linear relationships between $\dot{V}O_2$ and workload obtained along the tests. The identity line was closest to intercept and slope calculated for the test performed without any treadmill inclination (CPET0%). Differences between intercepts and slopes obtained for the other tests vs. theoretical values of 0 and 1, respectively, increased with the treadmill inclination. Hence, the physiological relationship between workload and $\dot{V}O_2$ along submaximal intensities was better described by CPET2% vs. CPET3.5% or CPET5.5%.

Discussion

This study investigated the potential influence of treadmill inclination applied during CPET ramp protocols on $\dot{V}O_2$max, ventilatory thresholds, and relationship between $\dot{V}O_2$ and workload in healthy adults of both sexes. In ramp protocols beginning with the speed corresponding to 50% of estimated maximal cardiorespiratory capacity, fixed treadmill inclinations from 0 to 5.5% degree did not influence $\dot{V}O_2$max outcomes. Overall, the duration of CPETs fell within the recommended range of 6–12 minutes (1,8,11). However, greater treadmill inclinations significantly shortened the tests (~50 and ~30% from CPET0% and CPET2%–CPET5.5%, respectively). The $\dot{V}O_2$ corresponding to VT1 slightly increased with treadmill inclination (~10% from CPET2% and CPET3.5% vs. CPET5.5%), whereas $\dot{V}O_2$ corresponding to VT2 remained stable across protocols. Finally, taking the identity line as reference, lower treadmill inclinations favored physiological relationships between $\dot{V}O_2$ and workload, which should be considered when designing protocols to analyze aerobic kinetics along progressive submaximal intensities.

To the best of our knowledge, this is the first study to investigate the influence of treadmill inclination on outcomes provided by ramp CPETs. The $\dot{V}O_2$max was not affected by inclination, but as previously mentioned, the duration of tests was significantly shortened, being of approximately 6 minutes in CPET5.5% vs. 13 minutes in CPET0%. It could be argued that this would be a too short duration to elicit a correct determination of maximal aerobic capacity. However, previous research comparing staggered protocols performed with different inclination suggested that $\dot{V}O_2$max might be correctly determined in tests shorter than 8 minutes (15,23). Astorino et al. (2) compared CPETs with different durations (short: ~6 minutes; average: ~10 minutes; and long: ~14 minutes) in healthy men and women. The $\dot{V}O_2$max was only slightly lower (~5%) in long vs. other protocols, again suggesting that CPETs of short duration may correctly assess maximal aerobic capacity. This premise agrees with data from the classic study by Buchfuhrer et al. (4), indicating that underestimation of $\dot{V}O_2$max would rather occur in too long (>17 minutes) than in quick tests. Shorter and longer CPETs might provide equivalent $\dot{V}O_2$max as long as workload increment (e.g., changes in treadmill speed and inclination) is adequate to avoid early peripheral fatigue (which evidently depends on the tested population).

The influence of treadmill inclination on the performance in ramp CPETs is unclear in the current literature. At first glance, differences between the presently applied inclinations may seem trivial. However, when calculating the tangent arc and adopting as parameter the relationship between slope percentages and their actual value in degrees, we remark that 2.0% slope corresponds to 1.1 degree–therefore, the actual difference between 2.0 and 5.5% inclination is of about 2.0 degrees. Just to illustrate, this value added to the 1.1 degree at 2.0% would correspond to a slope of 3.1 degrees in CPET5.5%. This is more than half of the inclination used as initial slope in the Bruce protocol [5.7 degrees or 10%], which has been criticized (and modified) for being excessive (14,27).

The analysis of previous studies about ramp protocols reveals that, on average, treadmill inclinations are of 12% (range 3.5%–27.5%), with speeds ranging between 3.2 and 14.0 $km \cdot h^{-1}$ (2,4,9,14–16,22,23,27). This is greater than the inclinations applied in our study. However, it is worthy to note that only 6% of our sample interrupted the test due to peripheral fatigue in CPET2%, 8% in CPET3.5%, and 9% in CPET5.5%. In the study by Myers et al. (22), the test was interrupted in more than 70% of subjects. However, precise information about treadmill inclination was unfortunately not provided. In any case, altogether, those data reinforce the premise that greater treadmill inclinations increase peripheral fatigue and tend to elicit early interruption of CPETs.

Other important information obtained from CPETs refers to ventilatory thresholds. Despite its controversial nature, these outcomes have been widely used in exercise intensity prescription and assessment of athletic performance. VT1 represents the abrupt increase of CO_2 concentration in relation to $\dot{V}O_2$, without compromising the continuity of exercise. VT2 is acknowledged as a marker of maximal lactate steady state (26), therefore representing a transition from vigorous to maximal exercise and reflecting inability to sustain intense exercise for long periods.

Midgley et al. (18) claimed that it would be possible to determine ventilatory thresholds by means of short-term ramp or pseudoramp protocols. However, we could not find studies investigating the isolated influence of treadmill inclination on these specific outcomes. Previous research comparing ventilatory thresholds obtained in different incremental test protocols focused on the modality of exercise (e.g., cycle ergometer vs. treadmill) (4,23) or type of protocol (e.g., ramp vs. staggered) (15,23). Our findings indicate that $\dot{V}O_2$ corresponding to VT2 was not influenced by treadmill inclination. However, this was not true for VT1. In fact, $\dot{V}O_2$ corresponding to VT1 was similar between protocols with lower inclination (68% $\dot{V}O_2$max in CPET2% and 69% $\dot{V}O_2$max in CPET3.5%), whereas significantly increased in CPET5.5% (76% $\dot{V}O_2$max). These data do not ratify previous research suggesting that the type of treadmill protocol would not influence VT1 (23). However, according to the literature, VT1 occurs within 40–75% $\dot{V}O_2$max (10). Assuming that VT1 reflects rather a range of intensity than a fixed point, one can speculate that albeit changes in treadmill inclination might influence this specific threshold, in practical terms, its values fell within the expected intensity range. In short, a variation of about 10% would probably not interfere in aerobic training prescription.

Finally, curves obtained from individual regressions calculated for each ramp protocol showed that relationships between $\dot{V}O_2$ and workload improved in lower treadmill inclinations. Indeed, the steeper the inclination, the greater the distance of slopes and intercepts from the identity line. Cardiopulmonary exercise testing performed with 0 and 2% degree inclination favored the analysis of physiological relationships throughout submaximal intensities, in comparison with those performed with 3.5 and 5.5% degrees. In addition, CPET0% and CPET2% exhibited higher r^2 and smaller SEE than the other 2 protocols. We could not find previous studies addressing the influence of treadmill inclination along ramp CPETs on $\dot{V}O_2$ vs. workload relationship.

The main limitation of this study was the utilization of the CRF questionnaire to determine the initial speed of CPETs because it has been suggested that the precision of this nonexercise model is lowered in individuals with high aerobic capacity ($>$55 ml$\cdot$kg$^{-1}\cdot$min^{-1}). However, bias due to this feature probably did not occur because $\dot{V}O_2$max in our sample was below this threshold. Moreover, our data refer to healthy and young individuals, which limit their extrapolation to older populations or specific groups, as those with cardiovascular disease. Finally, it is worthy to notice that although maximal aerobic capacity had been similar in CPETs performed with different treadmill inclinations, the best combination of speed and inclination to optimize the determination of $\dot{V}O_2$max and physiological relationships along submaximal workloads is yet to be determined. Further studies comparing other protocol designs in populations with different characteristics (age, sex, fitness, or clinical conditions) are therefore warranted.

In conclusion, our initial hypothesis was not ratified because $\dot{V}O_2$max did not differ across ramp CPETs performed with similar initial and final speeds, but different treadmill inclinations. The $\dot{V}O_2$ corresponding to ventilatory thresholds (VT1 and VT2) were also quite similar between protocols, with a small variation of 10% being observed only for VT1. However, linear regressions between workload and $\dot{V}O_2$ were closer to identity line in CPETs performed with smaller (CPET0% and CPET2%) than with greater (CPET3.5% and CPET5.5%) inclinations. Ramp protocols with lower inclinations seem therefore to favor the analysis of $\dot{V}O_2$ kinetics along submaximal workloads within incremental maximal CPETs.

Practical Applications

Altogether, our data suggest that ramp CPETs performed with inclinations of 0 and 2% degree should be preferred over protocols with greater inclinations, at least in healthy young adults. However, the test duration was about 30% longer in CPET0% than in CPET2% (13 vs. 9 minutes, respectively), which in practical terms may favor the choice of this latter protocol. In short, incremental ramp CPETs designed to last 8–12 minutes seem to be optimized when treadmill inclination is set at 2% degree. This information is useful for practitioners involved with aerobic exercise testing and prescription.

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