Larson et al. Int J Sports Exerc Med 2015, 1:3
ISSN: 2469-5718

International Journal of
Sports and Exercise Medicine

Original Research Article: Open Access

# Physiologic Responses to Two Distinct Maximal Cardiorespiratory Exercise Protocols

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## Abstract

**Purpose:** The purpose of this study was to compare physiologic responses elicited by a ramp protocol to those elicited by a staged protocol.

**Methods:** 57 subjects were recruited and consented to be tested on two separate occasions across one week using a magnetically-braked cycle ergometer. Expired gases were collected using a calibrated metabolic cart. Both protocols began at a workload of body weight (in kilograms; BWkgs.) in watts (W) and increased by 50% of BWkgs every 2 minutes or 1W every 2 seconds, for the staged and ramped protocols respectively.

**Results:** The staged protocol elicited a greater heart rate max (HRmax; $p<0.01$), minute ventilation (VE; $p<0.05$), time to exhaustion (TTE; $p<0.001$), blood lactate (La $p<0.001$), and blood lactate at 1-minute post exercise ($La^{-1}$ $p<0.01$), whereas the ramp protocol elicited a greater peak workload (PWL; $p<0.001$). Maximal oxygen consumption ($VO_2$max), gas exchange threshold (GET), and respiratory compensation point (RCP) were similar between protocols. Bland-Altman plots demonstrated strong agreement and minimal biases between protocols.

**Conclusions:** The results highlight different responses elicited by two distinct maximal cardiorespiratory exercise tests and indicate the importance of selecting the correct maximal exercise testing protocol; whether quantifying responses to maximal exercise or writing an exercise prescription. Interestingly, the ramp protocol elicited a similar $VO_2$max and a significantly greater peak workload in approximately half the time.

## Keywords

Oxygen consumption, Gas exchange threshold, Respiratory compensation point, Ramped exercise, Staged exercise

## Introduction

Maximal oxygen uptake, $VO_2$max, represents the functional upper limit of the cardiovascular system and is commonly regarded as a primary indicator of cardiorespiratory fitness [1]. Valid assessment of $VO_2$max requires that oxygen uptake fails to continue to increase despite an increase in workload, commonly described as a plateau (i.e., $VO_2$ plateau). The descriptive term "plateau" dates back nearly 100 years to the classical observations made by Hill and Luptin in 1923 [2]. However, the ability to reach a plateau is not common in all populations. In fact, Howley et al. [1] reviewed that the percent of subjects capable of achieving a plateau has ranged from ≤ 50% to 100%, and later specified to range from 30% to 95% [3]. Consequently, the appearance of physical exhaustion in the absence of a plateau influenced researchers to establish threshold values for certain physiological responses that when achieved could objectively constitute maximal effort. For example, attaining 1) a blood lactate value greater than 8mol $^* L^{-1}$ 2) a respiratory exchange ratio greater than 1.15, and 3) *some* percentage of maximal heart rate (HR) based on an estimation of age [1].

Maximal exercise testing is commonly performed on either a treadmill or a cycle ergometer with numerous protocol designs implemented for obtaining $VO_2$; two common designs being the staged (i.e., step) and ramped incremental protocols [4,5]. A staged incremental protocol increases the workload at set intensity values (e.g., 25 watts) following a defined interval of time as a series of "steps", typically every 2-4 minutes [6], until exhaustion. This design requires the individual to sustain a given workload for a predetermined interval of time, but allows the subject to reach a steady-state within each stage which can be important when measuring certain variables, such as blood lactate. On the other hand, the steps in intensity may not be appropriate for certain populations (e.g., clinical or less fit individuals) which may result in early test termination. Whereas a ramp protocol is characterized as a smooth "linear" increase, e.g., 1 watt (W) every 2 seconds, in workload throughout the test, and allow for obtaining $VO_2$ at gas exchange threshold, time constant for kinetics of $VO_2$, and work efficiency [7].

One early comparative investigation into four different maximal cycling test protocols reported no differences in any measurement across the four protocols [5]. However, discrepancies exist as to how the duration of the test stage influences overall performance with one report indicating shorter test durations with shorter test stages [8]. That being said, the relationship between an optimal test duration and peak $VO_2$ values has been shown [9].

Despite this, only a small number of studies have conducted comparative analyses of a staged and ramp protocol, and those

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**Citation:** Larson RD, Cantrell GS, Ade CJ, Farrell III JW, Lantis DJ, et al. (2015) Physiologic Responses to Two Distinct Maximal Cardiorespiratory Exercise Protocols. Int J Sports Exerc Med 1:013

**Received:** June 04, 2015: **Accepted:** July 01, 2015: **Published:** July 05, 2015

studies that can be found in the scientific literature employed relatively small samples [5], were interested in clinical populations [4], or compared different modes of exercise (i.e., treadmill vs. cycle) on lactate responses [10]. Therefore, it remains unclear how the progression in work rate as a relative “step” of work during a staged protocol might influence exercise outcome measures. For this reason, it was the intent of the present study to determine if a ramped protocol and a staged protocol utilizing increases in workload that was corresponded to body weight would produce similar physiologic and performance responses at maximal exercise. We hypothesized that subjects would be able to achieve a greater peak workload with the ramp protocol as a consequence of the smooth incremental work rate, but without affecting $VO_2$max values.

## Methods

### Subjects

Fifty-seven subjects of varying fitness levels participated in this study. Each participant was screened for cardiovascular conditions and orthopedic limitations according to the guidelines put forth by the American College of Sports Medicine before being enrolled using physical activity readiness questionnaire and a detailed medical history questionnaire. Participants provided informed consent that was approved by the Institutional Review Board at the University of Oklahoma, Norman, OK.

### Hydration status

Hydration status was measured using a refractometer (*VEE GEE Refractometer CLX-1*) and a sample of urine at the beginning of each visit. If urine specific gravity measured between 1.004 and 1.029, testing proceeded. If a lack of hydration was observed, the subject was provided water, and a subsequent hydration measurement was performed 30 minutes later. If a subject was unable to get within range after 30 minutes, they were rescheduled for a subsequent day.

### Maximal oxygen consumption protocols

Both maximal CPET protocols were performed on a magnetically braked cycle ergometer (LODE Excalibur Sport, The Netherlands) which subjects were carefully fitted to and recorded for subsequent retest purposes. Prior to testing, participants performed a 5 minute warm-up at low intensity (~25W). Expired gases were collected and analyzed using a reliable [11] metabolic cart that was calibrated before testing using room air and certified calibration gas (ParvoMedics® True One 2400; Sandy, Utah). $VO_2$ was collected breath-by-breath and quantified using a 30-second average. HR was measured continuously during the warm-up, exercise testing (recorded every two minutes), and immediately following each test until HR dropped below 120 beats per minute via a wireless chest strap monitor (Polar Electro, Lake Success, NY). Rating of perceived exertion (RPE) was measured according to the Borg 20-point scale (6: no exertion, 20: maximal exertion [12]) and recorded every two minutes.

### Staged protocol

The stage protocol began at a workload of 1.0 watt per kilogram of body weight ($W^{*}$ $BWkg^{-1}$) and increased by 0.5 watts per kilogram body weight every 2 minutes until they reached maximal exhaustion. Maximal exhaustion was defined as a pedal rate of <50 revolutions per minute (rpm) that could not be recovered.

### Ramp protocol

The ramp protocol began at a workload of $1W^{*}$ $BWkg^{-1}$ and increased by 1W every 2 seconds thereafter until maximal exhaustion was observed. Exhaustion was determined using the same criteria as that established for staged protocol.

### Blood lactate

Finger sticks drawing ~ 1.0µl of blood were performed at baseline, every two minutes throughout both tests, immediately post-exercise, and one-minute post-exercise to measure blood lactate concentrations via a reliable [13] portable lactate analyzer (LactatePlus; Nova Biomedical; Waltham, MA).

### Gas exchange threshold

Gas exchange threshold (GET) was determined using the V-slope method as previously described by Beaver et al. [14]. The V-slope method plots $VCO_2$ as a function of $VO_2$ and consists of a lower- and an upper-component. The lower component is represented by a slope of 0.8 to 1.0 and the upper component has a slope of greater than 1.15. The GET, initially regarded as anaerobic threshold [14], represents the point at which a given exercise intensity increases beyond a certain threshold resulting in a greater portion of energy provided through anaerobic metabolism [5]. In some individuals a second break point could be observed near the end of exercise which represents the respiratory compensation point (RCP); the point during exercise when ventilation increases out of proportion to $CO_2$ production.

### Statistical analysis

All statistical and power analyses were conducted using SigmaPlot 12.5 (*Systat Software Inc., San Jose, CA*). Dependent samples *t*-tests were conducted to determine differences in variables between the ramp and the standard protocol. Wilcoxon signed rank tests were performed when data was not normally distributed. Pearson product moment correlations were performed to quantify relationships between selected outcome variables. Cohen’s d effect size (ES) and statistical power were calculated for each variable. A value of ≤ 0.20 was considered a weak effect, 0.50 a moderate effect, and ≥ 0.80 a strong effect [15]. Bland-Altman plots (SigmaPlot 12.5) were created to determine agreement among variables [16]. Statistical power for measurements ranged from 0.14 to 1.00, with two measurements <0.50 (i.e., RER and $VO_2$).

## Results

### Subject characteristics

Subject characteristics are summarized in table 1. Fifty-seven (34 males and 23 females), healthy college-aged individuals (range: 18-37 years) with varying levels of physical activity ($VO_2$: 20-57ml $^{*}$ $kg^{-1}$ $^{*}$ $min^{-1}$) participated in the study. Of the 57 subjects originally enrolled three were omitted due invalid heart rate data as a consequence of equipment malfunctioning during one of the tests leaving a total of 54 subjects in our analysis. Of those 54 with complete data sets, five- (9%) and six (11%) individuals did not satisfy secondary [threshold] criteria for stage and ramp protocol, respectively.

### Secondary threshold criteria

Based on earlier studies demonstrating $VO_2$ plateaus being difficult to achieve in many individuals, we determined $VO_2$max was achieved if two of the three secondary threshold criteria were met i.e., *some* % of age-predicted heart rate max (90% herein; APMHR), post-test blood lactate ≥ 8mmol˙L$^{-1}$, and an RER ≥ 1.15 [for commentary see Howley et al. [1]. Of the 54 subjects with a complete data set 49 (90.7%) successfully met $VO_2$max criteria when performing the staged protocol and 48 (88.8%) met $VO_2$max criteria performing the ramp protocol. In particular, one subject failed to reach 90% APMHR and a lactate measurement of ≥ 8mmol˙L$^{-1}$, one failed to reach 90% APMHR, lactate measurement ≥ 8mmol˙L$^{-1}$, and a RER ≥ 1.15, two failed to obtain a lactate measurement ≥ 8mmol˙L$^{-1}$, and a RER ≥ 1.15, and the last subject failed to reach 90% APMHR and a RER ≥ 1.15 using the staged incremental protocol. On the other hand, three failed to achieve any of the secondary threshold criteria, two failed to

**Table 1:** Descriptive characteristics

| | Males (n=30) | Females (n=24) | Total (n=54) |
|---|---|---|---|
| Age (yrs.) | 22.77 ± 4.47 | 23.08 ± 5.58 | 22.91 ± 4.95 |
| Height (cms.) | 179.48 ± 6.75 | 164.63 ± 7.17 | 172.88 ± 10.14 |
| Weight (kgs.) | 78.35 ± 11.07 | 64.03 ± 11.13 | 71.99 ± 13.13 |
| BMI | 24.31 ± 3.07 | 23.50 ± 2.81 | 23.95 ± 2.96 |

Values are reported as mean ± SD. BMI: Body Mass Index.

**Table 2:** Physiological responses at maximal exercise to a ramped and a staged exercise testing protocol with associated percent differences and effect sizes. $VO_2max$: Maximal Oxygen Consumption, HR: Heart Rate; VE: Minute Ventilation, PWL: Peak Work Load, RER: Respiratory Exchange Ratio, RPE: Rating of Perceived Exertion, La: Blood Lactate, $La^{-1}$: Blood Lactate at 1 minute Post-Exercise, GET: Gas Exchange Threshold, RCP: Respiratory Compensation Point Values are reported as mean ± SD. Significantly greater than ramp protocol $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$; †significantly greater than staged p<0.001.

| | Staged | Ramp | Gain Score (Staged –Ramp) | %Difference | Effect Size |
|---|---|---|---|---|---|
| $VO_2max$ (ml · kg$^{-1}$ · min$^{-1}$) | 37.38 ± 8.52 | 38.05 ± 8.41 | -0.26 ± 2.20 | -0.02 | 0.01 |
| Max. HR (beats · min$^{-1}$) | 184.32 ±11.27$^{**}$ | 181.54 ± 11.77 | 2.81 ± 9.75 | 0.02 | -0.34 |
| Max. VE (liters · min$^{-1}$; BTPS) | 110.41 ± 35.07$^{*}$ | 105.58 ± 36.56 | 4.84 ± 15.96 | 4.37 | -0.16 |
| PWL (W) | 224.74 ± 62.96 | 254.54 ± 64.03† | -29.80 ± 23.29 | -13.26 | 0.44 |
| RER | 1.21 ± 0.09 | 1.23 ± 0.07 | -0.01 ± 0.07 | -1.65 | 0.25 |
| RPE | 17.39 ± 1.80$^{***}$ | 16.35 ± 2.40 | 1.04 ± 2.29 | 5.98 | -0.5 |
| Time (minutes) | 10.22 ± 2.6$^{***}$ | 6.59 ± 2.0 | 3.62 ± 1.56 | 35.52 | -1.60 |
| La (mmol · l$^{-1}$) | 7.39 ± 2.37$^{***}$ | 6.17 ± 2.25 | 1.22 ± 2.58 | 16.51 | -0.57 |
| Lactate$^{-1}$ (mmol · l$^{-1}$) | 11.28 ± 2.64$^{*}$ | 10.57 ± 2.45 | 0.71 ± 2.35 | 6.29 | -0.27 |
| GET (liters · min$^{-1}$) (n=42) | 1.85 ± 0.45 | 1.86 ± 0.41 | -0.01 ± 0.26 | -0.54 | 0.02 |
| RCP (liters · min$^{-1}$) (n=31) | 2.78 ± 0.62 | 2.71 ± 0.62 | 0.07 ± 0.41 | 2.52 | -0.11 |

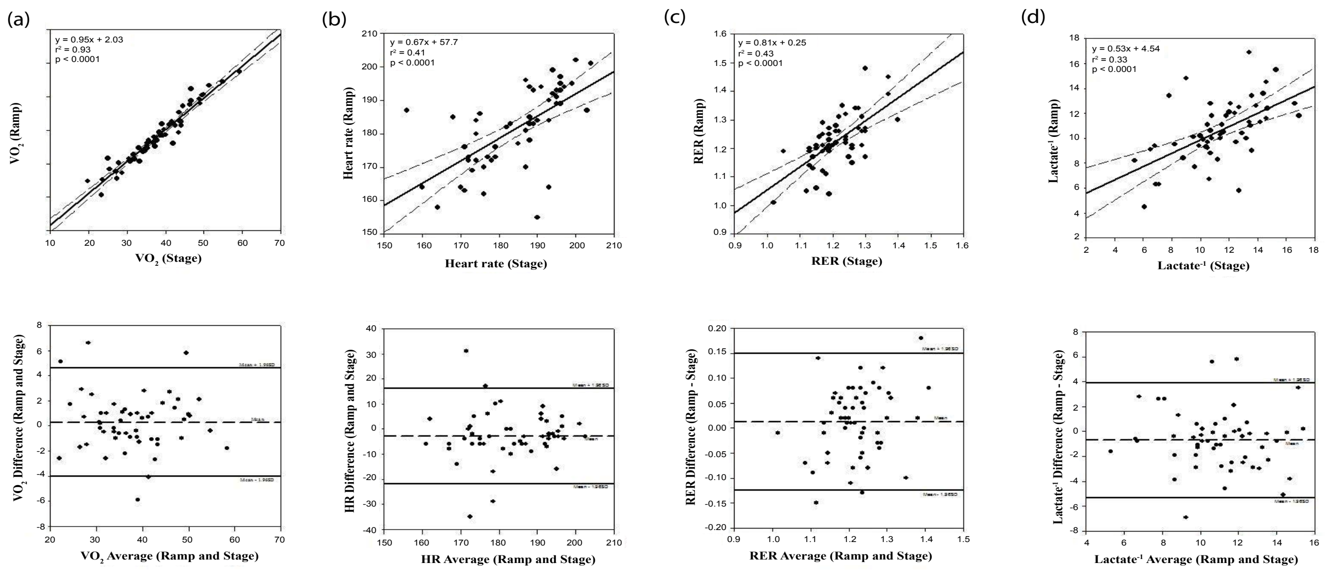


**Figure 1 a-d:** Pearson correlation (top) with Bland-Altman plots (bottom) of (a) $VO_2$, (b) heart rate, (c) RER, and (d) La-1 to a ramp and staged maximal exercise protocol. $VO_2$, oxygen consumption; RER: Respiratory Exchange Ratio; Lactate-1, blood lactate at 1-minute post exercise.

**Table 3:** Bland-Altman statistics. $VO_2max$: Maximal Oxygen Consumption, HR: Heart Rate, VE: Minute Ventilation, PWL: Peak Work Load, RER: Respiratory Exchange Ratio, RPE: Rating of Perceived Exertion, La: Blood Lactate, $La^{-1}$: Blood Lactate at 1 minute Post-Exercise, GET: Gas Exchange Threshold, RCP: Respiratory Compensation Point. ULA: Upper Limits of Agreement, bias + 1.96SD, LLA: Lower Limits of Agreement, bias – 1.96SD.

| | Bias ± SD (Ramp – Stage) | ULA | LLA |
|---|---|---|---|
| $VO_2max$ (ml · kg$^{-1}$ · min$^{-1}$) | 0.26 ± 2.2 | 4.58 | -4.05 |
| Max HR (beats · min$^{-1}$) | -2.78 ± 9.73 | 16.3 | -21.86 |
| Max VE (liters · min$^{-1}$; BTPS) | -4.84 ± 15.96 | 26.44 | -36.12 |
| PWL (W) | 29.80 ± 23.29 | 75.44 | -15.85 |
| RER | 0.01 ± 0.07 | 0.15 | -0.12 |
| RPE | -1.04 ± 2.29 | 3.45 | -5.53 |
| Time (minutes) | -3.62 ± 1.56 | -0.57 | -6.68 |
| Lactate (mmol · l$^{-1}$) | -1.22 ± 2.58 | 3.82 | -6.27 |
| Lactate$^{-1}$ (mmol · l$^{-1}$) | -0.71 ± 2.35 | 3.9 | -5.32 |
| GET (liters · min$^{-1}$) | 0.01 ± 0.26 | 0.53 | -0.51 |
| RCP (liters · min$^{-1}$) | -0.07 ± 0.41 | 0.74 | -0.88 |

achieve a lactate measurement ≥ 8mmol·L$^{-1}$ and a RER ≥ 1.15, and the last subject failed to achieve 90% APMHR and a lactate measurement of ≥ 8mmol·L$^{-1}$ using the ramp incremental protocol. Overall, of the 54 subjects analyzed 31 (57.4%) and 32 (59.2%) met all three secondary criteria using the ramp- and staged protocols, respectively.

## Physiological responses

Data are reported in table 2. No significant differences (p > 0.05) were observed between the ramp and staged protocol for $VO_2max$, respiratory exchange ratio (RER), gas exchange threshold (GET, n=42), and respiratory compensation point (RCP, n=31) at maximal exercise. Significant differences were observed for HRmax (Stage: 184.3 ± 11.3 vs. Ramp: 181.5 ± 11.8; ES: -0.34), RPE (Stage: 17.39 ± 1.8 vs. Ramp: 16.35 ± 2.4; ES: -0.5), VE (Stage: 110.41 ± 35.07 vs. Ramp: 105.58 ± 36.53; -ES: 0.16), PWL (Stage: 224.74 ± 62.96 vs. Ramp: 254.54 ± 64.03; ES: 0.44), TTE (Stage: 10.22 ± 2.56 vs. Ramp: 6.59 ± 2.04; ES: -1.60), La (Stage: 7.39 ± 2.37 vs. Ramp: 6.17 ± 2.25; ES: -0.57), $La^{-1}$ (Stage: 11.28 ± 2.64 vs. Ramp: 10.57 ± 2.45; ES: -0.27).

Pearson product moment correlation plots are reported in figures 1-3. With ramp plotted against staged: HRmax (r=0.64), $VO_2max$ (r=0.97), $La^{-1}$ (r=0.57), RER (r=0.66), VE (r=0.90), TTE (r=0.79), PWL (r=0.93), GET (r=0.81), and RCP (r=0.77) were significantly correlated between protocols (p<0.001). La (r=0.38) was also significantly correlated between protocols (p<0.01).

Bland-Altman statistics are reported in table 3 and plots in figures 1-3. Bland-Altman plots revealed homoscedastic data with minimal bias for the majority of measured variables demonstrating strong agreement between protocols.

## Discussion

Currently, few studies exist that have compared different maximal cardiorespiratory exercise testing protocols utilizing cycle ergometers [4,8,17,18]. Several different protocols are frequently implemented in maximal cardiorespiratory exercise testing, however, two commonly


ISSN: 2469-5718

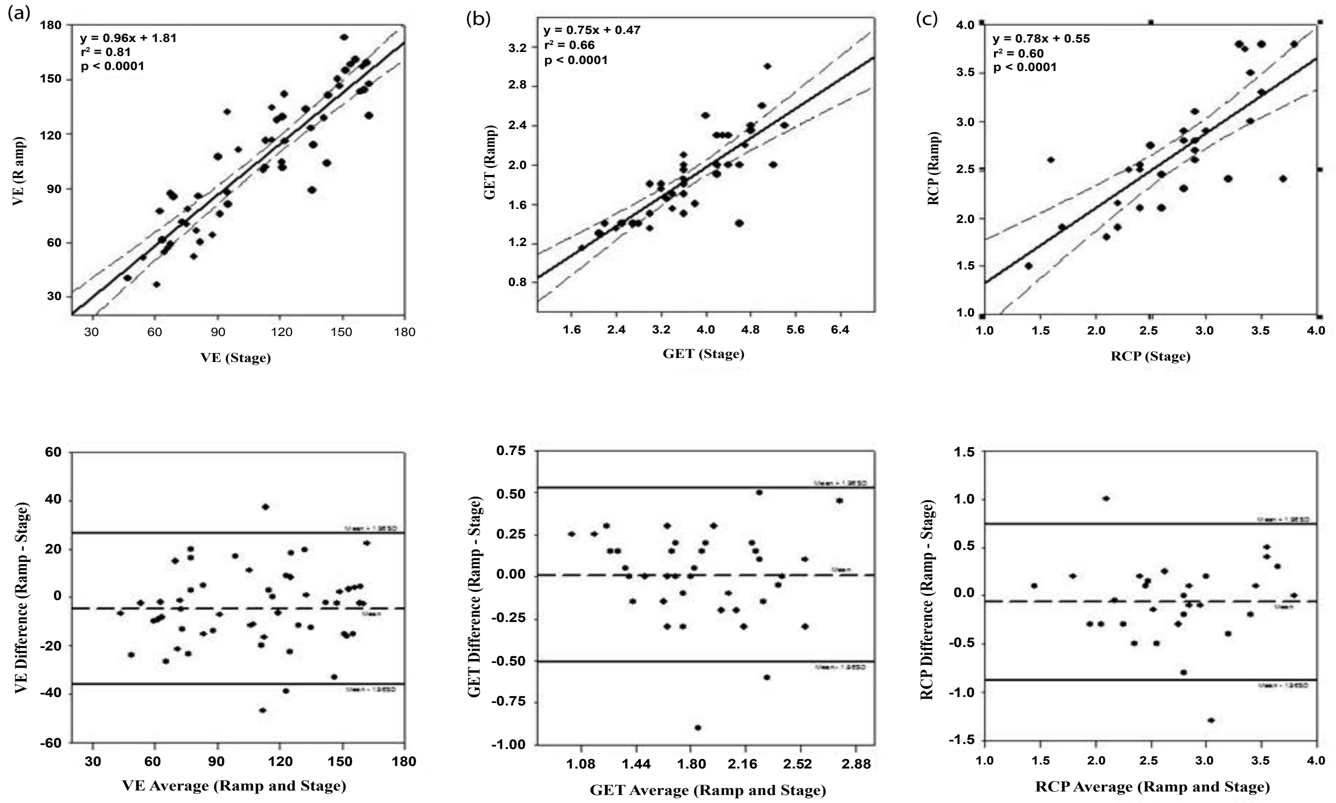


**Figure 2 a-c:** Pearson correlation (top) and Bland-Altman plots (bottom) for ventilatory responses to two maximal cardiorespiratory exercise protocols. VE: Minute Ventilation; GET: Gas Exchange Threshold; RCP: Respiratory Compensation Point.

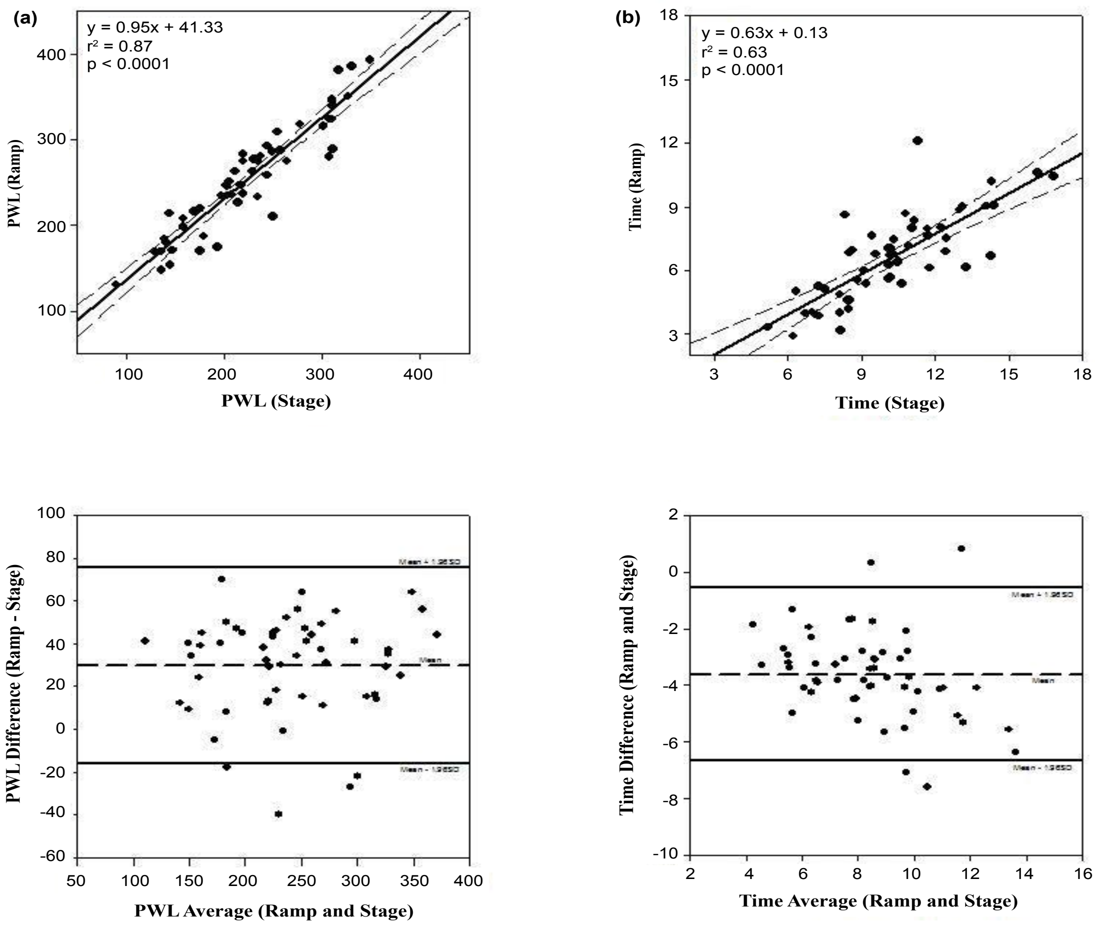


**Figure 3**: Pearson correlation and Bland-Altman plots for (a) PWL and (b) TTE during a ramped and staged maximal cardiorespiratory exercise protocol. PWL: Peak Workload; TTE: Time to Exhaustion.

used protocols include a ramped or a staged work rate [19]. Ramp protocols are characterized by a linear increase in workload whereas staged protocols increase "in jumps" (i.e., stages) following a defined interval of time. In the present study the ramp protocol consisted of an initial workload equal to one watt per the subject's body weight in kilograms ($W * BWkg^{-1}$) and progressed 1W every 2 seconds, while the stage protocol commenced identical to the ramp protocol, but increased by $0.5W * BWkg^{-1}$ every 2 minutes, until maximum exhaustion was observed. This particular staged design was selected based on pilot work (unpublished data) from our lab where we observed using an absolute increase in work rate, such as a 50W increase per stage for all subjects, resulted in untimely exhaustion in the majority of the smaller and/or less fit subjects. Therefore we decided to increase the staged workload relative to each individual's body weight (in watts). Not only was this design more tolerable with smaller and less fit individuals, it *may* also be beneficial in clinical populations, such as individuals diagnosed with cardiac disease [19] or neuromuscular limitations such as multiple sclerosis [20], who suffer from being severely deconditioned and may not be able to tolerate increases in work load disproportionate to their body weight and may be more successful with an individualized maximal exercise protocol. That being said, since clinical populations were not included in the study design this cannot be concluded with the present data.

Interestingly, despite the significant differences in HRmax (ES: -0.34) and time to exhaustion (ES: -1.60) between protocols, $VO_2max$ values did not differ between the protocols used in the present study, which is consistent with earlier studies [8,18]. On average, the staged protocol resulted in a HRmax value of 184.3 ± 11.3 bpm whereas the ramp protocol resulted in a value of 181.5 ± 11.8 bpm. These results are similar to others that compared 1- vs. 3-minute stages in males [18] and females [8], but disagrees with the work of Zhang et al. [5] who reported no differences in HR response between four different maximal cycle testing protocols [5]. Bishop et al. [18] and Roffey et al. [8] reported an average difference of 6.3 and 4.0bpm, respectively, between the 1- and 3-minute stages, while we observed a small yet significant difference of 2.8bpm between protocols. That being said, the work rate increase selected in Bishop et al. [18] and Roffey et al. [8] 3-minute stages equaled 25W and 30W, respectively; resulting in average test durations of 26 and 25 minutes and well beyond the recommended range provided by Buchfuhrer et al. [9]. On the other hand, the individualized two minute staged protocol used in the present study resulted in exhaustion at 10.22 ± 2.6 minutes which is within the recommended range of 8 -12 minutes [9]. Based on these results the two minute stage used in the present study appears more optimal than the three minute stages used previously in attaining exhaustion in an appropriate time frame, as well as support the use of either shorter duration stages (i.e., ≤ 2 minutes) or a ramp protocol if the desired outcome variable is $VO_2max$ [19].

The lactate response associated with both the protocols of the present study differed significantly immediately following each test (La) and remained significant one-minute post exercise ($La^{-1}$). Specifically, the staged protocol elicited greater blood lactate values at both time points (see Table 2 for mean ± SD and ES). One reason for this small but significant difference can be explained with data reported by Peronnet et al. [21]. Using an identical ramped work rate (i.e., 1W/2s) they reported a time delay in the accumulation of blood lactate of 6.23 ± 1.21minutes (range: 4.67-7.70 minutes), which beyond that delay blood lactate concentrations rose in a curvilinear manner [21]. The ramp protocol used herein elicited exhaustion in 6.59 ± 2.0 minutes, whereas the staged protocol used resulted in exhaustion at 10.22 ± 2.6 minutes. As a consequence of the time delay the measurement taken at the end of ramped work rate exercise in the present study most likely did not reflect actual lactate values within the exercising musculature [21], as it takes time to begin seeing accumulation of blood lactate levels. Therefore, based on these results it appears the ramp protocol used herein elicited exhaustion too early to measure an accurate lactate response in our subjects.

RER, the second most utilized criterion measure behind $VO_2$ plateau [22], has been previously reported to differ significantly between one- and three-minute stages (one: 1.23 ± 0.06 vs. three: 1.12 ± 0.02) using an increase in work rate of 30W per stage [8], but did not differ between a ramp and 1-, 2-, and 3-minute staged exercise protocols when the increase in work rate [for staged protocols] equaled that of the ramp protocol [5]. In the present study where the slope of the ramp protocol increased 1W/2s ($30W * min^{-1}$) and the staged equaled 50% of each subjects body weight (kg) in watts the RER values agree with the data of Zhang et al. [5]. For instance, they reported average values of 1.24 ± 0.07, 1.23 ± 0.05, 1.19 ± 0.05, and 1.17 ± 0.07 for their ramp and 1-, 2-, and 3-minute staged exercise protocols, respectively. Similarly, Poole et al. reported individual RER values ranging from 1.19-1.27 following a ramp protocol with a slope of 1W/3s (i.e., $20W^*min^{-1}$) in their analysis of secondary threshold criteria [22]. Therefore, the RER values of the present study along with those discussed [4,8] indicate RER responds similarly to a ramped and 1-, 2-, and 3-minute staged protocols in healthy individuals.

Previous studies comparing different maximal cycling exercise testing protocols have reported similar levels of perceived exertion in both healthy [8] and clinical populations [4]. This differs from the present results where the ramp protocol was perceived less strenuous than the staged protocol (ES=-0.5). One possible explanation may be the shorter amount of time spent during exercise which resulted in significantly less ventilation (ES=-0.16); or, possibly the abrupt increases in work load associated with the staged protocol convinced the subjects the test was more difficult.

Of note, the significantly greater PWL associated with the ramp protocol in significantly less time agrees with other studies that have investigated the effect of stage length during maximal exercise testing [4,8,23,24]. For instance, Roffey et al. [8] demonstrated shorter stages resulted in a greater peak workload (329.0 ± 46.78W vs. 270.25 ± 41.15W) in significantly less time (10.3 ± 1.56 vs. 24.93 ± 4.1 minutes) while still achieving a similar $VO_2$ in healthy individuals [8] while Myers et al. [4] demonstrated it in a cardiac patients. Based on the outcomes of $VO_2max$, RER, RPE, and PWL, it appears that some (clinical) populations may benefit from a similar ramped protocol.

We calculated the gas exchange threshold (GET) and respiratory compensation point (RCP) using the V-slope method described initially by Beaver et al. [14]. The average GET at $VO_2max$ in the present study was $1.86 L * min^{-1}$ and $1.85 L * min^{-1}$ for the ramp and staged protocol, respectively; which is similar to that of Zhang et al. who reported GET values of 1.94 ± 0.68 and 1.97 ± 0.69 for a ramp and 2-minute staged protocol [5]. The RCP on the other hand represents the point during exercise at which a disproportionate increase in ventilation (i.e., hyperventilation) occurs in relation to $CO_2$ production resulting in reduced arterial $CO_2$ levels. The present results indicate that RCP was observed at similar $VO_2$ values between protocols, but nearly 0.5L beyond the values of Zhang et al. [5]. In the work of Zhang et al. [5] RCP was reported as 2.25 ± 0.60 and 2.25 ± 0.67 L for the ramp and 2 minute staged protocol respectively, whereas RCP was observed at 2.71 ± 0.62 and 2.78 ± 0.62 L in the current study, however, this is likely the result of different levels of individual fitness between studies.

Bland-Altman plots demonstrated a strong agreement between the ramp and staged protocols for $VO_2$. This was evidenced through an average difference approaching zero, narrow LOAs representing minimal variability in data over a wide range of average $VO_2$ values (Table 3). On average, similar representations were observed for HR, RER, $La^{-1}$, GET, and RCP; each of which demonstrated small biases and LOAs between both protocols. On the other hand, agreement was not as strong for PWR, TTE, and La with an average difference of 29W, 3.7 minutes, and $1.28 mmol * L^{-1}$, respectively. Therefore, if any one of these latter variables is a primary desired outcome measure it is recommended to give careful consideration to the protocol selected as PWR was greater with the ramp protocol but La and TTE were greater with the staged protocol.

Blood lactate values tend to reach greatest values three to four minutes following maximal exercise [24]; therefore, one limitation in the present study was only measuring lactate for one minute post exercise which does not represent maximal levels. A second limitation involves the staged protocol used. During the early stages of data collection it became apparent the less fit subjects were not capable of working against a pre-determined absolute work rate. Therefore, it was determined to adjust the staged work rate to correspond in watts to half of their body weight in kilograms every two minutes, which to the best of our knowledge is a novel approach to individualizing maximal CPET protocols. Future work with exercise testing may consider implementing other percentages of body weight or possibly using a percentage of fat-free mass to determine work rate. Lastly, it should be noted that if the initial workload is too high there is a possibility the GET and RCP break points will not be evident. This phenomenon occurred in the present analysis and resulted in 42 subjects demonstrating a GET breakpoint and 31 subjects demonstrating a RCP breakpoint.

Overall, the ramp protocol appears to elicit similar physiological responses as the staged protocol. It is important to note, however, the greater peak workload achieved with the ramp protocol does not represent the highest maintainable workload and needs to be taken into consideration if testing for exercise programing and not the highest achievable workload. Therefore, if performing a maximal exercise test for exercise programming it is suggested to implement a staged protocol that will produce the greatest sustainable work load. Also of importance, the greater PWL associated with the ramp protocol was achieved in significantly less time which may be beneficial in severely deconditioned and/or clinical populations who cannot sustain exercise testing beyond 10 minutes [8], or find large jumps in resistance less tolerable. With respect to clinical and less fit individuals the ramp protocol may also be advantageous as it may be perceived as more tolerable while also providing similar end $VO_2$ values. Lastly, but of equal importance, the results of the Bland-Altman analysis demonstrate minimal biases, and a strong agreement (i.e., narrow limits of agreement) between the protocols for $VO_2$max, HR, RER, GET, and RCP.

## Acknowledgments

We would like to thank Shelby Shipman for her assistance in data collection, and all the participants who provided valuable time and effort.

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