Comparison of Sitting, and Sitting to Standing Cycle Ergometry versus Treadmill, on Cardiorespiratory Values in Adult Males and Females

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ABSTRACT

Kist WB, Laws R, Burgess K, Rizvi H, Glasheen, M.E., Dellwo, T. Comparison of Sitting, and Sitting to Standing Cycle Ergometry versus Treadmill, on Cardiorespiratory Values in Adult Males and Females. JEPonline 2013;16(1):95-104. The primary purpose of this study was to determine if standing on a cycle ergometer (CE) towards the conclusion of a graded exercise testing (GXT) would increase the CE cardiorespiratory values equal to the same treadmill (TM) values in recreationally-aerobically-trained subjects (11 males, 11 females) participated in this study. The subjects completed three GXT trials, one by TM, and two by CE. In one CE trial, the subjects remained seated throughout the GXT (Sit CE). In the other CE trial, initially-seated subjects stood up and pedaled after their RER was 1.0 (Stand CE). Sit CE-GXT and Stand CE-GXT cardiorespiratory values were statistically equivalent to the TM-GXT values in recreationally-aerobically-trained male and female subjects. On some cardiorespiratory variables, gender differences were likely caused by body composition differences between males and females. The encouraging findings of the present study suggest that, with further refinement of the “Stand CE” technique, it might become the method of choice in GXT in some populations.

Key Words: VO₂ Max, Exercise, Metabolic, Gender
INTRODUCTION

Graded exercise testing (GXT) is commonly performed using a treadmill (TM) or a cycle ergometer (CE) (4,7,14,19,33). Each exercise modality has advantages and disadvantages (2-4,7,36,39). The TM advantages are that individuals are more familiar with walking, jogging, and running. The increase in exercise confidence with the TM modality allows for an increase in maximal oxygen consumption (VO\textsubscript{2} max) ~25% higher compared to the CE-GXT modality (4,17,35). The most obvious TM disadvantages are the increased the risk of falling, the cost of the TM (4,33,39), and the difficulty in determining certain physiology measurements on the TM (46).

Conversely, the CE advantages are increased safety, less costly equipment, external workload is readily measured, and some physiological measurements (e.g., blood pressures, arterial blood samples, and cardiac output) are more easily obtained (1,4,46). The CE disadvantages include unfamiliarity with (bi)cycling, a predetermined pace is generally required for homogeneity and, most importantly, VO\textsubscript{2} max is of a smaller magnitude than when obtained by a TM-GXT. Yet, the TM is referred to as the traditionally more accepted GXT (gold-standard) modality (4,7,14,39).

Consistent with traditional protocol, the CE-GXT is performed with the subjects in the seated position (Sit CE), which is assumed to leave the upper body musculature inactive (10,33,46). It has been hypothesized, due to the increased energy required to support the trunk of the body and greater use of the arms during cycling, that standing should increase cardiorespiratory values (10,33,39). While standing up throughout an entire CE-GXT would likely not be tolerated by many non-athletic individuals unfamiliar with cycling, it may be possible for non-athletes to tolerate standing up towards the conclusion of the CE test (Stand CE). If this is possible, then, these individuals may actually increase their cardiorespiratory values (e.g., oxygen consumption, carbon dioxide production, minute ventilation, etc.) to levels equivalent to the values obtained by the TM-GXT (12,20,39).

In the Sit CE-GXT, maximal oxygen consumption (VO\textsubscript{2} max) and other cardiorespiratory variables are generally smaller in magnitude than that obtained with the TM-GXT in both males and females (23,39,42). While a few variables appear to be gender specific (25,31), there are concerns that may conflict with the oxygen kinetics response to a given modality. These variables include, but are not limited to, body position related biomechanical changes, types of muscle contractions (e.g., concentric vs. eccentric), and blood flow during contractions (23,24). The expectation that cardiorespiratory values, especially oxygen kinetics (23), will increase with the Stand CE-GXT approach has been minimally investigated (33).

Furthermore, it has not been investigated in a relatively homogeneous sample of recreationally aerobically trained males and females. Yet, if it could be demonstrated that Stand CE-GXT produces a cardiorespiratory value equivalent to that generated by the TM-GXT, it would offer a safer alternative to the TM-GXT. In short, if the Stand CE VO\textsubscript{2} max is equivalent in magnitude to the TM VO\textsubscript{2} max, it would be possible to use well-established TM norms for CE VO\textsubscript{2} max testing (4,20,33,46), especially since the CE norms are minimally established (19). Others agree that more research is needed to characterize the cardiorespiratory responses to TM-GXT and CE-GXT (18).

This study was designed to determine if: (a) the Stand CE-GXT could produce an equivalent cardiorespiratory value to that of the TM-GXT in recreationally aerobically trained males and females; (b) the Stand CE-GXT could produce a higher cardiorespiratory value to that of the Sit
CE-GXT; (c) there was an interaction between gender and exercise modality on cardiorespiratory values; and (d) there were any differences by gender and mode on oxygen kinetics markers.

**METHODS**

**Subjects**

A sample of 11 males (age = 24 ± 7.8 yrs; weight = 80 ± 11.4 kg) and 11 females (age = 23 ± 8.5 yrs; weight = 60.5 ± 4.1 kg) completed the study. Screening of subjects was done using the PAR-Q (4) and author-created medical and fitness questionnaires (4,33). The subjects that had no signs or symptoms of cardiorespiratory or metabolic disease, and had less than two cardiovascular risk factors were included.

This study included subjects who were engaged in regular aerobic exercise and who were familiar with both bicycling and running, although not all were currently exercising using both modalities. All GXTs complied with established data collection and safety guidelines (6,34,40).

The Institutional Review Board of the University prospectively approved the investigation. Informed consent was obtained from the subjects. This investigation was funded by the University and complied with Helsinki Declaration of 1975 for protection of human participants.

**Procedures**

Three GXT trials (counterbalanced sequence) were conducted. The TM trial used a programmable TM (Quinton ST-55 treadmill, Cardiac Science Corp., Seattle, WA) using the Bruce protocol (4,33,36). The other 2 trials (CE trials) used a mechanically-braked CE (Monark 828E, Vansbro, Sweden) following a protocol previously described (33). Both CE trials were MET-matched to the Bruce TM protocol (4,33). Before the CE trials, the subjects were acclimated to the CE that included a brief period of low-intensity cycling and practice in standing up while pedaling (33). The Stand CE trial required subjects to stand and pedal when their respiratory exchange ratio (RER) became 1.0 (unity).

The RER can be used to identify the terminal part of a VO2 max test (10,39,46). The RER typically becomes 1.0 at ~75% of VO2 max in most healthy individuals (33,46). The subjects averaged 3 to 4 min of standing during the Stand CE GXT (~last 25%). For the CE trials, the subjects were required to maintain a pedaling frequency (assisted via a metronome) at 60 rpm until their RER = 1.0 and, then, increase their pedaling rate to 70 rpm for remainder of the trial (17,33).

The cardiorespiratory values that were measured consisted of oxygen consumption (VO2), carbon dioxide production (VCO2), minute ventilation (VE), heart rate (HR), and related values (e.g., O2 pulse, VO2/HR, and respiratory exchange ratio, RER = VCO2/VO2) during pre-exercise, during GXT, and during post-exercise GXT trials. At least 2 days of rest occurred between the GXT trials, and the subjects did not eat for 2 hrs prior to the trial. Generally, GXT trials were conducted following a Tuesday, Thursday, and Tuesday pattern of being tested at approximately the same time of the day (5,8,15,33,41).

During the GXT, cardiorespiratory values were measured by a metabolic system (Medical Graphics Corporation “CPX-D” breath by breath system, St. Paul, MN) using 30 sec averaging methodology (6,36,46,47). During each GXT, 12-lead ECG (Quinton Q4500 12-lead ECG system, Cardiac Science Corp. Seattle WA) was monitored for safety and to obtain heart rate (HR) measurements.
When the RER = 1.0, and at VO\textsubscript{2} max, blood lactate (LT) was obtained via finger stick and measured (Accutrend Lactate, Sports Resource Group, Roche Diagnostics, Germany). Equipment was calibrated periodically throughout the investigation; whereas, the metabolic system analyzers (oxygen, carbon dioxide, and volume/flow) were calibrated immediately prior to each GXT (5,33,37).

### Statistical Analyses

Prior to statistical analysis, all GXT studies were reviewed for proper subject performance. Only subjects that gave maximal effort on trials were included in the statistical analyses (final N = 22). All data were screened for normality, univariate and multivariate outliers, and homogeneity of variance prior to statistical analyses (26) using SPSS version 17.0 (SPSS, Chicago, IL). Subject body characteristics (e.g., height, weight, and age) were analyzed per independent samples t test.

Data that were independent of body weight (e.g., HR max, RER max, HR@RER1.0, LT@RER1.0, LT max, VO\textsubscript{2} max in mL·kg\textsuperscript{-1}·min\textsuperscript{-1}, and METS max) were analyzed by a 2-way ANOVA (gender by trial with repeated measures on trials), while data directly weight-dependent (O\textsubscript{2} pulse, VCO\textsubscript{2}, and V\textsubscript{E}) were analyzed per ANCOVA (gender by trial, with repeated measures on trials, with weight as a covariate). Post-hoc testing was performed using the Tukey HSD method (26). The oxygen kinetics data (VO\textsubscript{2} mL·kg\textsuperscript{-1}·min\textsuperscript{-1} vs. time) was analyzed by a one way ANOVA by trial for each minute, and the slope of the VO\textsubscript{2} vs. time data for minutes 2 to 10 was calculated using linear regression (38) and was graphed (Sigma Plot 8.0 (SPSS Inc). For all analyses, the level of significance was set at P<0.05.

### RESULTS

Independent samples t tests demonstrated (Table 1) that body weight was different by gender (P=0.001), but age was not (P=0.97). Two-way ANOVA demonstrated statistically significant differences by gender, but not trial on VO\textsubscript{2} max (P=0.001) and METS max (P=0.001). Two-way ANCOVA demonstrated significant differences by gender, but not trial on V\textsubscript{E} max (P=0.001) and O\textsubscript{2} pulse (P=0.001). However, carbon dioxide production (VCO\textsubscript{2}) was different by gender (P=0.001) and trial (P=0.002) with TM data greater than both CE trial data, but there was no interaction (P=0.38). There were no statistical differences on the following cardiorespiratory values: HR max (P=0.28), HR@RER1.0 (P=0.08), RER max (P=0.448), LT@VO\textsubscript{2} max (P=0.81), and LT@RER1.0 (P=0.60).

Power values for the crucial cardiorespiratory variables were generally adequate (ideal power range = 0.50-0.80) (26) VO\textsubscript{2} max = 0.91, V\textsubscript{E} max = 1.0, VCO\textsubscript{2} max = 1.0, HR max = 0.43, HR@RER1.0 = 0.65, METS max = 0.90, and RER max = 0.32. The oxygen kinetics data (Figure 2) were not statistically different by trial until after the 12th min. The slope (a.k.a. unstandardized beta coefficients) (38) of the VO\textsubscript{2} vs. time curves between 2 and 10 min were: males (TM = 6.12 mL·min\textsuperscript{-1}, Stand CE = 5.7, Sit CE = 6.30) and females (TM = 8.1 mL·min\textsuperscript{-1}, Stand CE = 7.2, Sit CE = 4.8).
**TM, VO₂ Max Trial**

- Preparation of participant & Familiarity with exercise equipment
- VO₂ Max test begins
- At RER of 1.0 = lactic acid obtained
- @ VO₂ Max lactic acid obtained

0 (min) 10 20 2 d rest ⇒ Next trial

**Stand CE, VO₂ Max Trial**

- Preparation of participant & Familiarity with exercise equipment
- VO₂ Max test begins
- At RER 1.0 = lactic acid & stand up on cycle ergometer
- @ VO₂ Max lactic acid obtained

0 (min) 10 20 2 d rest ⇒ Next trial

**Sit CE, VO₂ Max Trial**

- Preparation of participant & Familiarity with exercise equipment
- VO₂ Max test begins
- At RER 1.0 = lactic acid & remain seated
- @ VO₂ Max lactic acid obtained

0 (min) 10 20 2 d rest ⇒ Next trial

**Figure 1. Study Design for the 3 Exercise Trials.** TM, Treadmill, VO₂ Max, maximal oxygen consumption; Stand CE, standing cycle ergometer, Sit CE, sitting cycle ergometer, RER, respiratory exchange ratio; d, days; and min, minute(s).
Table 1. Subject Characteristics and Cardiorespiratory Variables by Gender and Trial.

<table>
<thead>
<tr>
<th>Variables</th>
<th>MALES</th>
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<th>FEMALES</th>
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<td></td>
<td>Treadmill</td>
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<td>Sit CE</td>
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<td>Sit CE</td>
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<td>Age (yrs)</td>
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<td>23 ± 8.5a</td>
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<td>Weight (kg)</td>
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<td>60.5 ± 4.1b</td>
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<td>METS (max)</td>
<td>14.3 ± 3.0a</td>
<td>13.0 ± 2.6a</td>
<td>13.0 ± 2.7a</td>
<td>12.0 ± 1.9b</td>
<td>10.8 ± 1.9b</td>
<td>11.0 ± 2.1b</td>
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<td>VO₂ max (mL·kg⁻¹·min⁻¹)</td>
<td>54.8 ± 10.5a</td>
<td>49.9 ± 9.0a</td>
<td>51.3 ± 9.6a</td>
<td>39.9 ± 7.0b</td>
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<td>HR@RER1.0 (beats·min⁻¹)</td>
<td>146 ± 17a</td>
<td>142 ± 22a</td>
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<td>148 ± 14a</td>
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<td>HR max (beats·min⁻¹)</td>
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<td>O₂ pulse (mL·bt⁻¹)</td>
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<td>LT@RER1.0 (mg·dL⁻¹)</td>
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<td>LT@VO₂ max (mg·dL⁻¹)</td>
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<td>RER max</td>
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<td>1.20 ± 0.10a</td>
<td>1.16 ± 0.11a</td>
<td>1.23 ± 0.10a</td>
<td>1.23 ± 0.0a</td>
<td>1.22 ± 0.0a</td>
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<tr>
<td>VCO₂ max (L·min⁻¹)</td>
<td>4.86 ± 0.54a</td>
<td>4.20 ± 0.35a</td>
<td>4.0 ± 0.73a</td>
<td>3.10 ± 0.59b</td>
<td>2.72 ± 0.58b</td>
<td>2.83 ± 0.55b</td>
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METS max, maximal metabolic equivalent; VO₂ max, maximal oxygen consumption; HR@RER1.0, heart rate when the respiratory exchange ratio was unity; HR max, maximal heart rate; O₂ pulse, oxygen consumption/heart rate; LT@RER1.0, lactate when the RER was unity; LT@VO₂ max, lactate at VO₂ max; VCO₂ max, maximal carbon dioxide production; and V̇E max, maximal minute ventilation. Values reported are means ± standard deviations. Values with different subscripts were statistically different (P<0.05).
DISCUSSION
Comparison of Stand CE vs. TM
The primary purpose of this investigation was to determine if Stand CE cardiorespiratory values could be made equivalent to those obtained by TM-GXT in recreationally aerobically trained adult males and females. The statistical results support the hypothesis, given it was found that Stand CE cardiorespiratory values, within gender, were statistically equivalent to the TM on the following cardiorespiratory values (refer to Table 1): METS max, HR max, LT@VO₂ max, RER max, VE max, and VO₂ max. To the best of the authors' knowledge this is the first report, using our novel “Stand CE” technique, where Stand CE cardiorespiratory values were statistically equivalent to TM cardiorespiratory values. This finding that the Stand CE-GXT cardiorespiratory values were statistically equal to the TM-GXT cardiorespiratory values is generally in disagreement with many Sit CE vs. TM investigations (4,7,8,11,18,27,33,45).

Figure 2. Oxygen Kinetics by Trial and Gender. Lines of best fit were drawn using last 30 sec of each minute.
The finding that the Stand CE cardiorespiratory value was equivalent to the TM cardiorespiratory value contrasts with our previous work using the Stand CE technique where the TM cardiorespiratory value was statistically greater than the Stand CE cardiorespiratory value (33). However, that investigation used a diverse population of age and training status, which included both sedentary and aerobically trained subjects. It is suspected that the TM equivalent to the Stand CE cardiorespiratory data shown in this investigation is likely due to the subjects being recreationally aerobically trained. That is, the male TM VO₂ max (54.8 ± 10.5) was greater than the 90th percentile for age, and the females TM VO₂ max (39.9 ± 7.0) was greater than the 80th percentile for age (19,20). Aerobically fit subjects are likely to do well exercising using different modalities, especially for a brief period of time, even considering the effects of specificity of training (10,13,20,39).

Exceptions to specificity of training are common in aerobically trained individuals where some oxygen kinetic markers have been found to be independent of mode of exercise (7,8,13,16). The hypothesis that the subjects’ fitness level is important in explaining our VO₂ max findings by mode of exercise is supported by a study which used recreationally aerobically trained males to test mode of exercise (TM vs. Sit CE) on respiratory markers and showed equivalent VO₂ max data by mode (15). In that study, several ventilation markers (ventilatory-equivalent for CO₂, Vₑ max, and tidal volume) were greater on the CE (Sit CE) versus TM, and those ventilation findings contrast with the ventilation findings of the present study (Table 1).

Percentagewise, the TM VO₂ max values were about 10% greater than the Stand CE VO₂ max for both males and females. In a study comparing Sit CE versus TM, using similar aged (to this study) males and females, and using the TM as the reference, it was found that the male Sit CE VO₂ max was = -9% and females = -11% less than the TM VO₂ max (43). In another study comparing Sit CE to TM using only females (ages = 17 to 40 yrs), the CE VO₂ max was = − 8% of the TM VO₂ max (31). Likewise, in a study utilizing an electronically-braked CE it was found that female Sit CE VO₂ max was = -21% and male Sit CE was = -21% of TM VO₂ max (25). In a study using recreationally aerobically trained males, it was found that the CE VO₂ max values were approximately 85% of the TM VO₂ max values (18). Another study demonstrated that the VO₂ max data may be equal between CE and TM (15). Using trained cyclists and runners, it was shown that male runners Sit CE VO₂ max was = -16% and female Sit CE VO₂ max was = − 9% of TM VO₂ max values (16). In a study using gender-pooled data from trained cyclists and runners, it was shown that cyclists Sit CE VO₂ max was = − 6% while the runner Sit CE VO₂ max was = −10% of TM VO₂ max (7). Thus, on a percentagewise basis, the findings of the current study, comparing TM VO₂ max to CE VO₂ max, is better than some, but similar to most studies.

Physiologically, it is hypothesized that VO₂ max increases when standing up and pedaling, even for a short period of time, because additional muscle mass is recruited in order to support the trunk of the body and the use of the arms (support and leverage) during vigorous cycling (4,10,39). Indeed cross-country skiers are frequently shown to have the highest VO₂ max values and this is thought to be due to their use of greater muscle mass (39). As would be expected from greater usage of muscle mass and increased VO₂ during GXT, it is to be expected that VCO₂ max and Vₑ max would proportionally increase (10,46). In the present investigation, consistent with the ~10% greater TM VO₂ max versus Stand CE data, TM VCO₂ max and TM Vₑ max (Table 1) data were also approximately 10% higher in the TM trial versus Stand CE trial. However, again, these trends in VO₂ max, VCO₂ max, and Vₑ max of the present investigation contradict the findings of the previously cited study where CE ventilation variables were greater than TM values (15). In summary, on a statistical basis, Stand CE VO₂ max values were equivalent to TM cardiorespiratory values, but on a percentage basis Stand CE data were less than the TM data.
Comparison of Stand CE vs. Sit CE

The second purpose of this investigation was to demonstrate that Stand CE cardiorespiratory values would be greater than Sit CE cardiorespiratory values. The findings of this investigation demonstrated a lack of statistical difference, within gender, between the Stand CE and Sit CE cardiorespiratory values on the following variables (Table 1): METS max, HR max, LT@VO2 max, RER max, VO2 max and VE max. This was an unexpected statistical finding. It was hypothesized that the Stand CE cardiorespiratory values would be greater than the Sit CE cardiorespiratory values because of the greater energy used in standing during CE (10,32,33). But, interestingly, the finding that the Stand CE cardiorespiratory values were equivalent to the Sit CE values is consistent with several studies using aerobically trained subjects (22,32,33,42). It is probable the finding that Stand CE is equivalent to Sit CE cardiorespiratory values is due to the fact that these recreationally aerobically trained subjects would perform well independent of the mode of exercise (13).

An alternate explanation for the lack of statistical difference in cardiorespiratory values between the Stand CE and the Sit CE GXT might have been that standing up when the RER was 1.0 may have been too late in the GXT to maximize the response of the aerobic energy systems to the increased weight-bearing load (5,10,33,39). Heavy reliance upon anaerobic mechanisms may have already occurred at that point. (5,12,39,46). There is some evidence that the availability of anaerobic reserves may be influential in reaching VO2 max on a CE (18). Unfortunately, anaerobic testing, per either TM or CE (9), was not performed in this investigation.

Another plausible explanation for the lack of an increase in the cardiorespiratory values during the Stand CE versus the Sit CE might be related to biomechanical factors (4,30). Did standing up and holding on to the handlebars put the lower extremity in a more efficient position for greater torque production at a similar oxygen cost of work? Consistent with this hypothesis, anecdotally, several subjects reported that it was awkward, that the workload (resistance, not pedaling frequency) on the CE should have been further increased, at the instant that they stood up and began to pedal using their body weight as an advantage to generate torque. There are inconsistent findings regarding the biomechanical effects of sitting versus standing in cycling reported in the literature (22,32,42). It is hypothesized that technical refinement to the Stand CE protocol, such as standing up on the CE at a slightly lower RER, or at the nadir of the ventilatory-equivalent (46) for oxygen (e.g., V_E/VO2), before the accumulation of significant amounts of lactic acid, may result in an increase in VO2 max and other cardiorespiratory values. If this were the case, it is still unlikely that many non-aerobic subjects would be able to stand throughout the entire CE-GXT as this would be similar to high intensity continuous aerobic work (39). More technical modifications to optimize the Stand CE technique are therefore warranted.

Comparison of Mode and Gender

The third purpose of this investigation was to determine if the cardiorespiratory values differed by mode and gender (interaction). As shown in Table 1, the gender-related data, such as METS max, VO2 max, V_E max, VCO2 max, and O2 pulse all demonstrated males having greater values than females. This finding was expected (10,39). Likewise, the cardiorespiratory values where males and female values were expected not to differ, such as HR max, RER max, and LT@RER1.0 held true. Two-way ANOVA and ANCOVA demonstrated no statistical interaction between gender and mode. The gender findings of this investigation are consistent with other investigations (4,17,43,44). These findings are likely explained mostly due to male versus female body composition. Males have more muscle mass. Females have more body fat. Males have greater myoglobin and hemoglobin concentrations (in this age group). Males also have larger Type I fibers (slow oxidative) (23,39).
**Oxygen Kinetics by Mode and Gender**

The final purpose of this investigation was to determine if there were gender and/or mode of exercise differences in some oxygen kinetics. This requires the assessment of the physiological mechanisms responsible for the dynamic uptake of oxygen during exercise (23,24). For example, more oxygen kinetics investigations are indicated because of the factors that limit VO₂ at the onset of exercise. The question of how closely lung VO₂ matches muscle VO₂ shortly after the onset of exercise, and the cause of the steady increase in muscle VO₂ under different work conditions remain poorly understood (23). It is important to understand the determinants of oxygen kinetics to improve both athletic performance and the quality of life of healthy and diseased males and females using different exercise modes (18,23,24).

As illustrated in Figure 2, oxygen kinetics, as defined in this study (VO₂ per time) was shown to be independent of exercise mode and gender until the higher VO₂ levels were achieved. The slopes of the regression lines for the subjects were especially similar by trial and gender (slope = males TM = 6.12 mL·kg⁻¹·min⁻¹, Stand CE = 5.68, Sit CE = 6.30; females TM = 8.20 mL·kg⁻¹·min⁻¹, Stand CE = 7.23, Sit CE = 4.8) between minutes 2 and 10. This finding is especially interesting because the types of muscle contractions are known to be different between CE and TM with Sit CE contractions being predominately concentric, while TM contractions have a large eccentric component (4,13,16,23). However, TM muscle contractions may become more concentric as the load (especially grade) increases (18). The Stand CE muscle contractions likely represent a hybrid situation where there is a larger eccentric component than Sit CE, but less than TM (12,18). However, in contrast to the especially linear portion (minutes 2-10) of the oxygen kinetics curve, the later portion of the curve demonstrated a statistically significant effect of gender that was independent of body size between males and females with males having greater values than the females. Although measuring relative VO₂ (mL·kg⁻¹·min⁻¹) adjusts for body weight, it may be that it does not correct for muscle mass (10,29,39). That is, if fat-free mass had been measured in the present investigation with a very accurate method (e.g., hydrostatic weighing or DEXA), it might be that the gender difference in VO₂ would have been minimized or eliminated if VO₂ were standardized per millimeter per kilogram of fat-free mass.

**LIMITATIONS**

One limitation of this study was that not all of the subjects in all trials exercised to a “true” VO₂ max using the classic VO₂ max criteria, where a plateau (Figure 2) in VO₂ (150 mL·min⁻¹) is achieved despite an increase in workload (5,10,39,46). In contrast, the GXTs in this study were terminated when the subjects could no longer keep pace with the TM or when the subjects’ pedaling rate (CE trials) fell below 60 rpm, or when the subjects reached exhaustion and requested to stop the test (5,6,8,10,18,33). That is, in short, the subjects exercised to VO₂ peak and not VO₂ max (46). Despite this limitation though, approximately 85% of the subjects’ absolute VO₂ data increased less than 150 mL·min⁻¹ in the immediate minute preceding reaching their highest VO₂ value. Additionally, 80% of the subjects’ VO₂ increased less than 150 mL·min⁻¹ in the second minute preceding their highest VO₂ value. The somewhat misleading appearance of a lack of a plateau in VO₂ versus time graph in some trials (notably the TM males, Figure 2) is mostly due to the reduced number of subjects who made it beyond minute 12 being included in the “line of best fit” calculations. However, it has been recently shown that the ability to reach a plateau in VO₂ max is dependent upon exercise modality (18). The incidence in demonstrating a plateau per CE is only 8% while 58% per TM in recreationally trained males. The lack of plateau, especially on CE, might be related to fatigue within the muscle itself (i.e., the type of muscle fibers being utilized, Ia vs. IIX, or the type of motor units recruited) with incidence of fatigue being greater in CE versus TM (23).
Furthermore, using secondary VO\textsubscript{2} max criteria (e.g., an RER greater than 1.15, LT greater than 8.0 mmoles·L\textsuperscript{-1}, and less reliably 85% of HR max) for reaching a “true” VO\textsubscript{2} max, (21,28,33) for all trials and gender, the mean RER max was greater than 1.15, the mean LT@VO\textsubscript{2} max was greater than 8.0 mmoles·L\textsuperscript{-1} (except for the male Sit CE 7.4 ± 4.2 mmoles·L\textsuperscript{-1}), and the mean HR max was greater than 85%, (except for the female Stand CE trial, which HR was 84% of HR max). Percentage HR max is probably not a good indicator of VO\textsubscript{2} max especially if one calculates HR max as 220 – age, as this equation over estimates HR max for this age group (4). Another reason for having a lack of confidence in percentage HR max being an indicator of reaching VO\textsubscript{2} max is that the differences in HR at VO\textsubscript{2} max can vary substantially in the same groups per mode (TM vs. Sit CE) of exercise (16,43). Treadmill versus Sit CE HR differences, with TM having a greater HR max, has been shown in other studies including non-aerobically trained (TM vs. Sit CE HR difference; males = 6 beats·min\textsuperscript{-1}; females = 27 beats·min\textsuperscript{-1}) and trained (TM vs. Sit CE HR difference; males = 17 beats·min\textsuperscript{-1}; female = 9 beats·min\textsuperscript{-1}) participants (16,43). Thus, it is believed that the vast majority of GXT VO\textsubscript{2} max values in the present investigation were at or close to being a true VO\textsubscript{2} max. Our VO\textsubscript{2} max findings are most consistent with a recent study, using recreationally trained subjects that a plateau in VO\textsubscript{2} max had a low incidence, but secondary criteria were generally achieved (18).

Another limitation may have been that a mechanically-braked CE, compared to an electronically-braked CE, was used in this study (33). Electronically-braked CE allow workload to be maintained relatively independent of pedaling frequency (33,36). Related to the type of CE used, another limitation was that step-wise (non-continuous) workload protocols for both the TM (Bruce) and CE (Bruce-matched) versus ramping protocols were used (3-5,10,19,33). The Bruce protocol is well-studied and one of its primary disadvantages is that the step increases between its 3-min intervals are relatively large (3 METS/stage) (3,46). It could be that the increase in workload near the terminal portion of the GXT (Figure 2) was too large for some participants and had ramping protocols been used for both the TM and CE, smaller increments in load may have allowed a more classical flattening (plateau) of the VO\textsubscript{2} versus time curve would have been demonstrated. Having better control of and smaller increments in workload might have clarified the findings in the present study (4,5,33,35-37). However, this point is debatable since most studies generally show that ramped-CE cardiorespiratory values are lower than ramped-TM cardiorespiratory values (5,21,33,35,39).

CONCLUSIONS

The results of this study indicate that the crucial Stand CE cardiorespiratory values were statistically equivalent to the TM cardiorespiratory values. Likewise, the crucial Stand CE cardiorespiratory values were statistically equivalent to the Sit CE cardiorespiratory values. It is probable that these findings are the result of both the male and female subjects having a relatively high aerobic fitness level. It is likely that refining the Stand CE technique using strategies such as standing up at a lower RER, increasing the resistance (vs. the cadence) at the instant of standing up during the Stand CE test will increase the Stand CE cardiorespiratory values equivalent to the TM cardiorespiratory values and allow the Stand CE cardiorespiratory values to become greater than the Sit CE cardiorespiratory values. It was also shown that there were gender differences on some cardiorespiratory values (i.e., males greater than females), but there was no interaction between exercise mode and gender. Finally, the oxygen kinetics data for moderate to high-moderate levels of exercise was shown to be similar by exercise mode and gender.

The findings of the present study are encouraging in that technical refinement of the Stand CE-GXT protocol and/or technique may result in an increase in the cardiorespiratory values (especially VO\textsubscript{2} max) and thus, meet the first two goals of this investigation. In this regard, further refinement of the
Stand CE-GXT is warranted. Being able to obtain the CE cardiorespiratory values that are statistically and percentagewise equivalent to the TM cardiorespiratory values, with CE’s concomitant safety and physiological monitoring advantages, may lead to the Stand CE-GXT technique becoming the preferred method of GXT (33). In addition, the focus of future investigations will be to add a fourth GXT trial that focuses on the 3 classic phases (I, II, & III) of oxygen kinetics. This GXT trial should use 3 to 10 min workloads at submaximal exercise intensities such as 40, 60, and 80% of VO₂ reserve, which are intensities below, at, and above the anaerobic threshold (10,20,23,46). A final goal will be to validate the findings of the present investigation in less-healthy populations (e.g., asthma, obesity, and diabetes).

ACKNOWLEDGEMENTS
The authors would like to thank Joshua Mitchell for his intermittent, but extremely important, participation in various stages of data collection. We would also like to thank Jordan Powell for his graphing efforts.

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