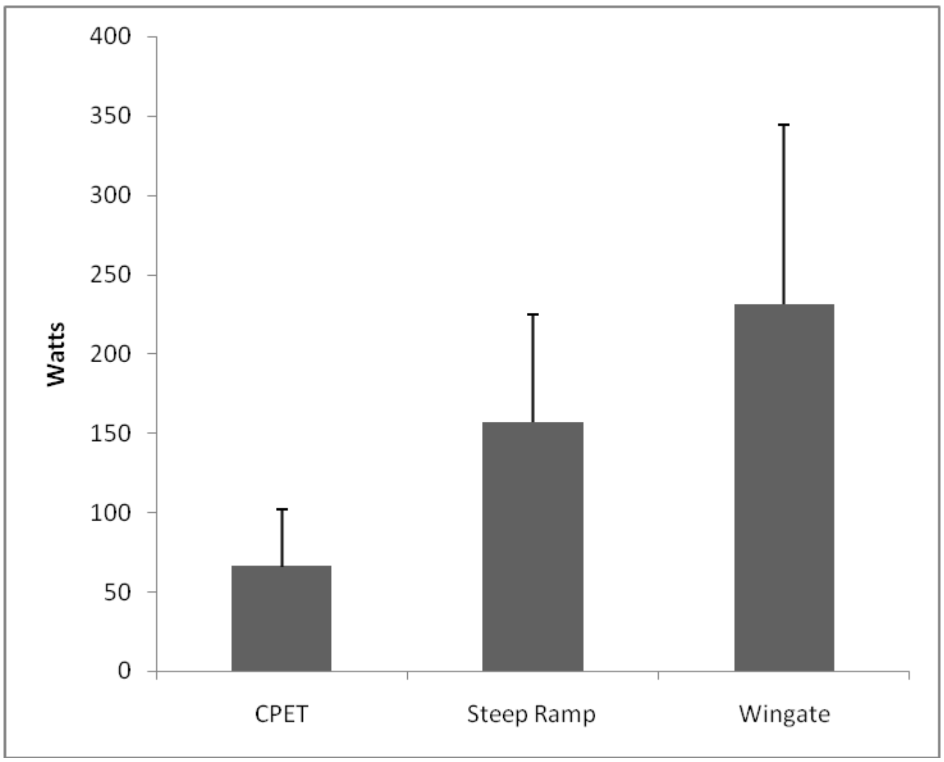

Figure 3.1: Comparison of the cardiopulmonary exercise test peak power (CPET), the steep ramp test peak power, and the average power in the 30-second Wingate anaerobic test in watts. Results are presented as mean ± standard deviation.

difference between the WAT (7 ± 2) and the SR (5 ± 2) RPE for dyspnea. There were no differences in RPE in regards to leg fatigue between the tests. Between test data are presented in Table 3.1.

3.1.1.2 Correlations

Pearson r analyses of work rates revealed significant correlations between SR_{peak} and both the $CPET_{peak}$ and the W_{avg} ($r = 0.887$ and 0.887 respectively). $CPET_{peak}$ and W_{avg} were also found to have a significant correlation ($r = 0.795$).

Many ventilatory parameters for the SR were found to correlate significantly with the CPET and WAT such as VO_2 ($r = 0.891$ and 0.939), VCO_2 ($r = 0.837$ and 0.926), V_T ($r = 0.907$ and 0.954), EELV% ($r = 0.905$ and 0.873), and IRV% ($r = 0.916$ and 0.880). V_{Epeak} also correlated well with its respective power output for each of the tests (CPET $r = 0.855$, WAT $r = 0.797$, SR $r = 0.940$). RER on the SR correlated with RER on the WAT ($r = 0.615$).

3.1.1.3 Reliability

The WAT and the steep ramp test were both performed twice to ensure the data was reliable. W_{avg} and SR_{peak} correlate well from one day to the next ($r = 0.966$ and 0.991 respectively), and Bland-Altman plots were used to determine the equality of the data and the magnitude of differences in measurements between the 2 sessions (See Figures 3.2 and 3.3). Means and standard deviations of the work rates are presented in Table 3.2.

3.1.2 Power Analysis

Study sample size analysis focused on the power outputs for each of the tests. Since the SR test was of principal interest in this study, it was compared to each of the other tests separately with a 2 sample comparison of means to determine power of the study. When the SR_{peak} and WAT_{avg} are used in a two-tailed test of significance, the power of the study is 46.3%. When the SR_{peak}

Table 3.1: End-exercise measures for cardiopulmonary exercise test (CPET), steep ramp test (SR), and Wingate anaerobic test (WAT) presented with means and standard deviations.

End-Exercise Measures	**Tests**		
	CPET	SR	WAT
PWR (CPET & SR) Wavg (WAT)	65.9 ± 35.9	156.8 ± 67.9*†	231.2 ± 113.4*
VO_2 (L/min)	1.11 ± 0.46	1.07 ± 0.41	0.99 ± 0.45
VCO_2 (L/min)	1.13 ± 0.52	0.97 ± 0.40	0.90 ± 0.42*
V_E (L/min)	40.4 ± 13.3	38.9 ± 13.0	39.7 ± 14.7
RER	1.00 ± 0.13	0.90 ± 0.07*	0.89 ± 0.08*
V_T (L)	1.19 ± 0.31	1.12 ± 0.24	1.09 ± 0.33
V_T/IC (%)	76.5 ± 13.0	70.1 ± 12.0*	70.4 ± 13.8
IC/TLC (%)	24.1 ± 4.7	25.1 ± 5.5	23.5 ± 4.0
EELV/TLC (%)	75.9 ± 4.7	74.9 ± 5.5	76.5 ± 4.0
EILV/TLC (%)	94.0 ± 4.7	92.0 ± 5.1	92.9 ± 4.2
IRV/TLC (%)	6.0 ± 4.7	8.0 ± 5.1	7.1 ± 4.2
RR (breaths per minute)	34 ± 6	35 ± 8	37 ± 8
SpO_2 (%)	91.5 ± 3.0	92.3 ± 1.5	93.3 ± 3.9

*indicates significant difference from CPET. †indicates significance from WAT. PWR=peak work rate, VO_2=oxygen consumption, VCO_2=carbon dioxide elimination, V_E=minute ventilation, RER=respiratory exchange ratio, V_T=tidal volume, IC=inspiratory capacity, TLC=total lung capacity, EELV=end expiratory lung volume, EILV= end inspiratory lung volume, IRV=inspiratory reserve volume, RR=respiratory rate, SpO_2=oxygen saturation.

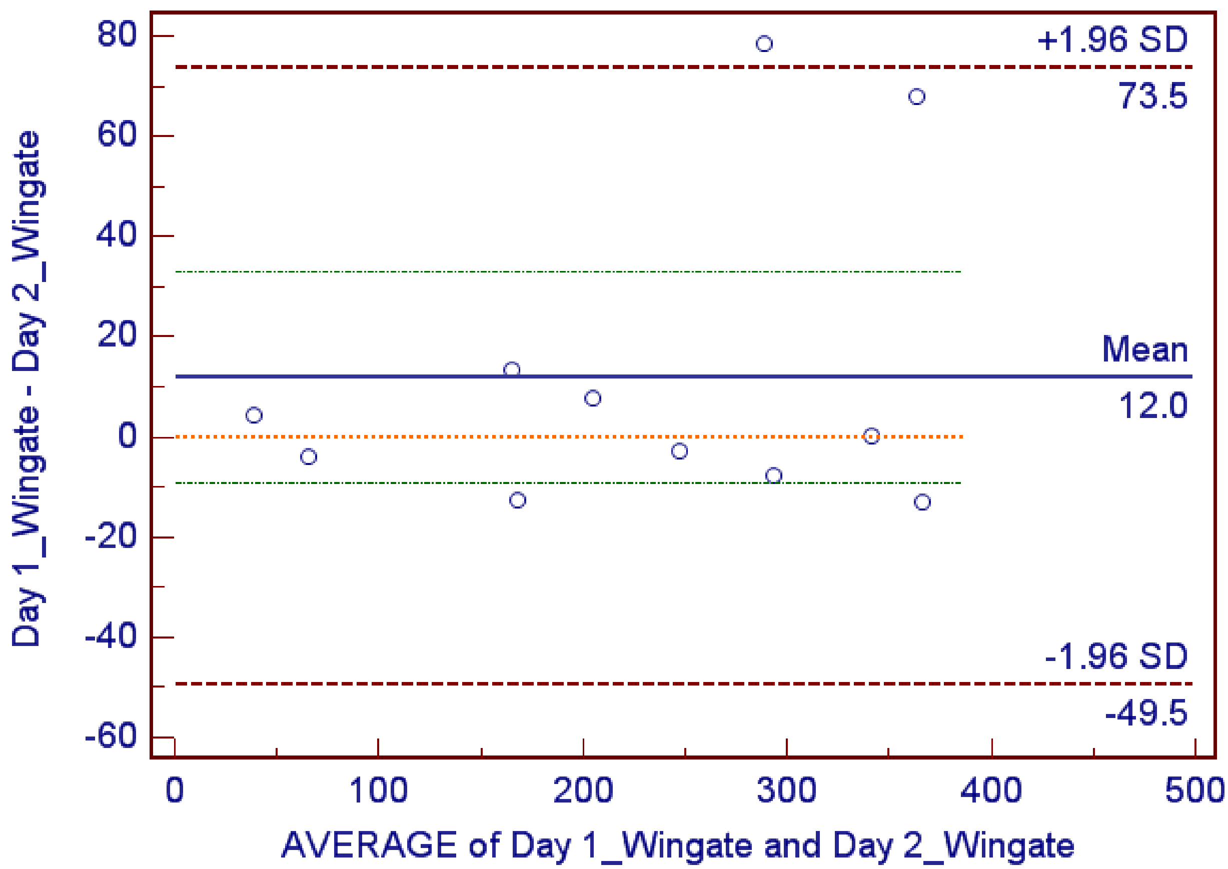

Figure 3.2. Bland-Altman plot of reliability of Wingate average power measurements (W_{avg}) between both sessions. Y-axis: The difference between W_{avg} from one day to the next. X-axis: The average of W_{avg} between both days.

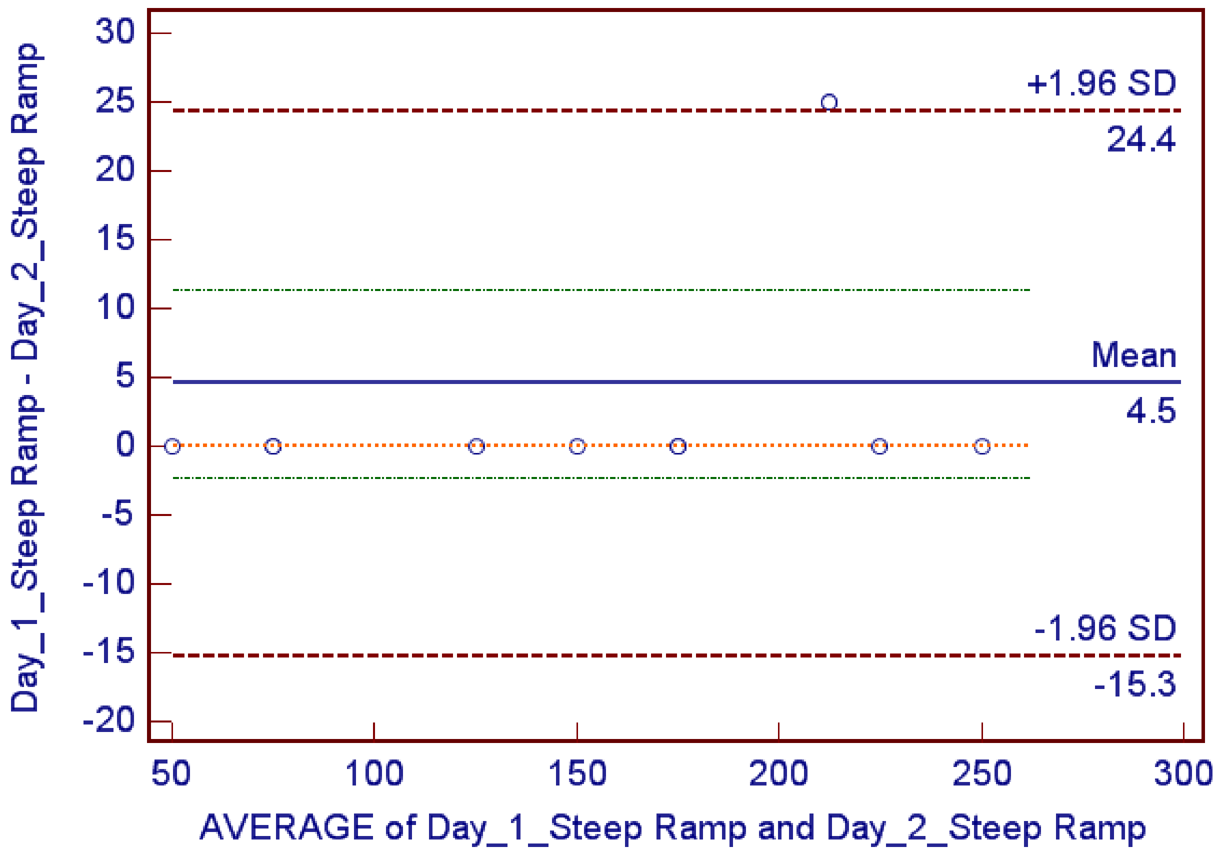

Figure 3.3. Bland-Altman plot of reliability of the steep ramp peak power measurements (SR_{peak}) between both sessions. Y-axis: The difference between SR_{peak} from one day to the next. X-axis: The average of SR_{peak} between both days.

Table 3.2: Correlation of work rates recorded over 2 sessions presented with means and standard deviations.

	Wingate Average Power	Steep Ramp
Day 1 (watts)	237.2 ± 119.1	159.1 ± 70.1
Day 2 (watts)	225.2 ± 109.6	154.6 ± 66.0
Pearson r correlation	0.966	0.991

is used in conjunction with the $CPET_{peak}$ in a one-tailed test of significance, the power of the study is 98.9%. Although these results are very dissimilar, they reflect the vast differences in the standard deviations for each of the tests. The CPET used in combination with the steep ramp test indicates good power because it would not be difficult to assess differences between these means with low standard deviations. The reverse is true when considering the steep ramp with the WAT because of the large mean and standard deviation associated with the WAT.

3.2 DISCUSSION

3.2.1 Introduction

The purpose of this study was to compare the power outputs and physiological outcomes between the tests and determine if the steep ramp test better reflects aerobic or anaerobic exercise in COPD patients. The findings illustrate that higher power output is achieved in the SR and WAT compared to the CPET (156.8 ± 67.9, 231.2 ± 113.4, 65.9 ± 35.9 W respectively), while there are no differences in VO_2, V_E, IC%, IRV% and RR during the 3 tests. These findings indicate that similar ventilatory restrictions exist for all 3 tests despite the different work rates attained. Although SR_{peak} and W_{avg} correlate well with each other, they also both correlate with the aerobic $CPET_{peak}$. These findings together suggest that performance on the 3 tests is more reflective of the degree of ventilatory limitation attained, than of the type of energy system utilized. Nonetheless, the short amount of time to complete the SR test (67 ± 27 seconds) (American College of Sports Medicine, 2001) and the high power output suggests that the SR is a reasonable test of anaerobic power despite the ventilatory limitations.

3.2.2 Peak work rate

This study supports the assertion that leg power is often underestimated in the traditional incremental design of the CPET and is frequently terminated before a maximal muscular response has been achieved due to ventilatory limitations (Butcher & Jones, 2006; Vogiatzis et al., 2004; Vogiatzis et al., 2005; Meyer et al., 1996). The first hypothesis is supported by the fact that the CPET produced the lowest work rate followed by the SR and WAT respectively. According to the findings, prescription of exercise intensities of 100% $CPET_{peak}$ (66 ± 35 W) is not quite 50% of the SR_{peak} ($SR_{50\%}$) scores (78 ± 34 W). This is comparable to the findings of Meyer et al (1997) that $SR_{50\%}$ is approximately equivalent to 90-100% $CPET_{peak}$ in chronic heart failure patients. The variation in findings may be related to differences between the diseases or the severity of the cardiopulmonary limitations between groups. In this sample, prescription of 100% CPET PWR for interval training underestimates what is achievable by these patients. Ideal intensities for interval training are unknown for this population, but if 60-70% of the SR_{peak} was appropriate for intensity prescription then the CPET falls short of being useful. If exercise prescription is based on the measure of maximal leg power achieved during a test, then testing should more accurately reflect what the patient is capable of accomplishing.

The W_{avg} was significantly larger than the SR_{peak} and may be partially related the design of the tests. The WAT includes more speed and momentum at the beginning of the test, and the SR uses increments to ramp up to maximal power. The high speed and momentum at the beginning of the WAT encourages high peak power and facilitates continued work to the end of the 30-second test, thus driving up the average power. In contrast, the SR builds incrementally from 25W, at a relatively slow rate, to a patient limited maximum. It is difficult to determine the exact contribution of each energy source (PCr, glycolysis, or aerobic metabolism) during exercise. However, maximal exercise is still primarily fueled by anaerobic glycolysis at approximately 60 seconds (American College of Sports Medicine, 2001). The average time to complete the SR test was approximately 60 seconds (67 ± 27 seconds) and therefore the test may be assumed to be predominantly anaerobic in nature.

The second hypothesis appears to be supported by the significant correlations between the SR and the WAT in regards to power output (r = 0.887) despite the mean differences in power found between the tests. However, the hypothesis is ultimately not supported because the CPET also correlates well with the SR and the WAT (r = 0.887 and 0.795 respectively) despite producing the lowest power output and being a test of aerobic, rather than anaerobic, power. This illustrates that the correlations may not indicate a similarity between the tests in regards to the predominant energy system.

3.2.3 Limitations of ventilation

The fact that the patients reached similar maximal ventilation in all 3 tests was not anticipated, and does not support the third hypothesis. Ventilatory constraint at end-exercise is indicated by an inability to increase V_T due to dynamic hyperinflation (O'Donnell, Revill, & Webb, 2001), and by nearing predicted maximal ventilation EELV and EILV increase, IRV decreases, and an increasing V_T during exercise occupies a large percentage of IC (O'Donnell, Revill, & Webb, 2001). It was assumed that the patients would be limited by ventilatory constraint during the CPET, in part due to the relatively long period of time they were exercising. Therefore, it was also assumed that they would hyperinflate less, demonstrate less ventilatory constraint (ie. increased ventilatory reserve), and be limited more by peripheral muscle performance during tests lasting only 30-90 seconds. However, despite the varying exercise durations, the similar level of ventilatory restriction observed in the 3 tests suggests this may be the limiting factor in all of the tests. This common limitation may be the reason why there are significant Pearson r correlations between $CPET_{peak}$, SR_{peak} and W_{avg} (SR_{peak} vs $CPET_{peak}$ r = 0.887, SR_{peak} vs W_{avg} r = 0.887, $CPET_{peak}$ vs W_{avg} r = 0.795).

There were no differences in the separate measurements of IC% and V_T between the tests. However, the combination of the CPET's slightly smaller IC% and a slightly larger V_T, compared to the SR, translates into a statistically significant difference in the percentage of IC used as V_T (76.47 ± 12.98% and 70.06 ± 11.95% respectively). The absolute difference of approximately 52 milliliters is not clinically important as demonstrated by the similar RPE for dyspnea recorded between the CPET and SR (6 ± 2 and 5 ± 2, respectively). Taken together with other lung volume measurements, this finding suggests no difference in ventilatory constraint between the CPET and SR.

The previous studies that have used the SR test (Meyer et al., 1996; Meyer, Schwaibold et al., 1996; Meyer et al., 1997; Puhan et al., 2006) have not evaluated lung volumes and dynamic hyperinflation during the test. Meyer et al (1996, 1996, 1997) used the SR test with chronic heart failure patients who become short of breath during exercise due to the inefficiency of the heart to pump blood; therefore, lung volumes were likely not outcomes of interest. Puhan et al (2006) used the SR test for COPD patients, but the test was used to set intensities for interval training rather than evaluating lung hyperinflation.

It is difficult to compare these results with prior work as there is a paucity of research examining lung volumes during short-term exercise tests in COPD. Interval training studies may allow some comparison because the work intervals approximate the time it takes to complete the WAT and SR. Vogiatzis et al (2004) used 30 second intervals in their study of COPD patients and found a higher IRV at end-exercise during interval exercise compared to continuous exercise. This is not similar to the findings of this study since subjects in both the SR and the WAT had very little IRV remaining at end-exercise. However, Vogiatzis et al used 100% PWR based on a typical incremental exercise test. The higher work rates attained using the SR and WAT in this study may have contributed to increased hyperinflation. Also, if end-exercise measures in the Vogiatzis study were obtained at the end of a rest interval, it is possible that IRV had increased as the patient recovered from peak exercise.

3.2.4 Metabolic outcomes

Oxygen debt recovery by the aerobic system is necessary in order to replace the ATP that has been depleted by maximal anaerobic exercise, or exercise that has exceeded the anaerobic threshold (American College of Sports Medicine, 2001). The high levels of lactic acid must be buffered in order to restore the body to a less acidic state. The respiratory system acts quickly by releasing more CO_2 to assist this process (American College of Sports Medicine, 2001). The high VCO_{2peak} in the CPET (1.13 ± 0.52 L/min) is likely an indication of the patients exceeding anaerobic threshold towards the end of a relatively long period of exercise of increasing intensity. The VCO_{2peak} in the WAT (0.90 ± 0.42 L/min) is the lowest of the 3 tests which may be an indication of the pH buffering just beginning to occur in that short time period. The steep ramp VCO_{2peak} (0.97 ± 0.40 L/min) seems to fall in between the other 2 values, and although not significant, would seem to indicate that despite the fact that the steep ramp test was much shorter in duration than the CPET, the higher work rate may have contributed to an increase in the anaerobic system's contribution towards the end of exercise. Also, the increased time of the SR may have allowed enough time for buffering to occur. The short duration of the WAT may have contributed to the lower VCO_{2peak} recorded during that test. If VCO_{2peak} was recorded even a few seconds after completion of the WAT, there may have been more time for the body to fully buffer the lactic acid and the values may have been similar to the SR or CPET. Despite the significant difference in VCO2peak between the CPET and the WAT, there were no significant differences in RER between the 3 tests. The correlation of RER between the SR and the WAT (r= 0.615) reflects the similarities in metabolic measurement at peak exercise between the two tests. However, as discussed above, if measurements were taken just a few seconds after the completion of the WAT then perhaps VCO2peak and VO2peak – and thus RER – measurements would have been more similar to the SR and the correlation may have been higher.

Although RR and SpO_2 were the same between tests at end exercise, an anecdotal observation was that SpO_2 often decreased slightly during recovery of the steep ramp and more so during the WAT. Given the ventilatory limit that was achieved at end exercise in all 3 tests, and the fact that the patients had an inability to increase ventilation much further at that point, it is not surprising that SpO_2 would begin to decrease as the body tried to overcome the oxygen debt sustained during anaerobic exercise. Patients could more easily recover from the CPET, a slow incremental test, because they could stop when they felt themselves approaching maximum effort. With anaerobic exercise, once the short period of intense exercise is over, the body must replace the spent ATP and rid itself of waste products (American College of Sports Medicine, 2001). Ventilation must increase as a result of lactic acid buffering during recovery and if the patient is already at their maximum ventilation, they face a difficult recovery even after they have stopped exercise.

Collection of recovery data may have provided meaningful data in order to understand the metabolic and ventilatory changes during the period of recovery from oxygen debt. Unfortunately, the patients became somewhat claustrophobic at the end of exercise when they were struggling to catch their breath. The need to reduce anxiety in order to assist the patients to recover safely became paramount and the breathing apparatus was removed.

Although similar ventilatory constraint was found between all 3 tests, the RPE for dyspnea was significantly higher for the WAT than the SR test. This may be a reflection of the difficult recovery observed after the WAT. Logistical issues such as removal of the breathing apparatus and patient anxiety and exhaustion made it impossible to ask the patients about their RPE right at the end of exercise for the WAT. The patients were asked approximately 30 seconds-1 minute after the end of the test to comment on their end of test dyspnea and leg fatigue, which may have been tainted by their difficult experience of oxygen debt recovery during the delay.

3.2.5 Limitations

There are a few limitations to this study. There were many exclusion criteria so the results may not be generalized to those individuals who would have been excluded according to the criteria set out in Chapter 2. Many COPD patients use supplemental oxygen at rest or during exercise which could have altered results or helped them to recover more easily from the exercise tests compared to those patients who do not use supplemental oxygen. That exclusion criterion on its own severely limited the sample from which to draw subjects.

According to the classification of lung function impairment discussed in chapter 2, there were 2 patients in this study with moderate impairment, 8 patients were defined as having severe impairment, and 1 patient had very severe impairment. Therefore, since most of the subjects had at least severe impairment of lung function, these results may only be generalized to that classification of patients. Also, these trained patients were recruited from a pulmonary rehabilitation program where they were familiar with exercise and desensitized to fatigue, pain and dyspnea. They were comfortable with their limitations and were perhaps not as anxious as other unconditioned patients may have been.

CHAPTER 4
CONCLUSIONS

4.1 SUMMARY

The findings of this study indicate that, patients with COPD elicit similar degrees of ventilatory constraint during the SR test as in both the CPET and WAT tests, despite the significantly different power outputs obtained across the 3 tests. The power output on the SR, albeit statistically lower than the average power on the WAT and the short duration of the SR test suggest that peak SR power best reflects anaerobic power. Meyer et al (1996, 1996, 1997) have presented the SR test as a useful tool to prescribe interval training intensities, but it had not previously been evaluated against both aerobic and anaerobic tests to determine the type of exercise energy system it reflects. Furthermore, it has not previously undergone analysis in regards to lung volume measurements in COPD patients.

The traditional CPET used to test COPD patients has many uses, but it appears to be imprecise in assessing peak power capabilities of the lower extremity muscles. More recent literature has focused on prescribing higher work rates for aerobic exercise in the form of interval training. Patients are able to perform the same amount, or more total work, than continuous exercise with fewer symptoms. $CPET_{peak}$, or a high percentage of $CPET_{peak}$ has been used to prescribe intensity. However, the low work rates achieved in the CPET may underestimate the patients' abilities for interval exercise. A test of anaerobic power may be more suitable for prescribing interval exercise in order to increase the potential for training benefit in COPD patients.

The highest PWR was found in the WAT but the patients found the test to be especially demanding. Patients typically control their effort by monitoring their shortness of breath during exercise but by the nature of anaerobic exercise, that is not possible with the WAT. The patients gave maximal effort during the test without realizing the degree of dyspnea they would incur as they tried to overcome the oxygen debt at the end of exercise. The SR test seems to be an appropriate compromise between the low PWR of the CPET and the high PWR, but demanding recovery, of the WAT. The SR test reflects anaerobic type power while allowing the patients to manage their symptoms.

Interval training is attractive for those patients who become very short of breath during aerobic exercise. Pulmonary rehabilitation programs will likely follow the more recent research and begin to use interval training in an effort to improve the fitness of their participants. It allows patients to improve their fitness dramatically with similar, or decreased, symptoms. Anaerobic training may be used as an adjunct to aerobic endurance training but likely should not replace it completely in pulmonary rehabilitation. The CPET is therefore still useful for determining baseline status, determining the cause of exercise limitation, and prescribing aerobic exercise. The SR test is a useful clinical test for prescribing anaerobic interval intensity. However, the WAT is very difficult for patients and should likely be used in select situations.

Further research is required to determine what percentage of SR_{peak} may be tolerated in interval training. Other research may focus on determining protocols for interval training in COPD including, duration of work and rest intervals, intensity of resting intervals, overall exercise time, and number of workouts per week.

4.2 CONCLUSIONS

4.2.1 Hypothesis 1.3.2.1 (The SR test PWR and the 30-second WAT average work rate will be higher than the CPET PWR.) was supported by the experimental evidence. The work rates were significantly different from each other with the W_{avg} and SR_{peak} being higher than the $CPET_{peak}$.

4.2.2 Hypothesis 1.3.2.2 (The SR test will reflect anaerobic energy utilization by correlating well with the 30-second WAT.) was not ultimately supported due to the fact that all 3 tests correlated well with each other. The correlation may not be an indication of the similarity of energy systems expressed during exercise.

4.2.3 Hypothesis 1.3.2.3 (The COPD patients will experience less ventilatory constraint at the end of the SR test and 30-second WAT, compared to the CPET.) was not supported by the evidence. The patients experienced a similar level of ventilatory constraint in all 3 tests.

APPENDIX 2
PULMONARY REHABILITATION SCHEDULE

Frequency: 3 days per week

Duration of session: 1 hour

Group warm up (20 minutes):

- Low intensity aerobic warm up
- Stretching
- Balance exercises
- Strengthening with resistance bands

Individual aerobic activity (40 minutes):

- Individuals may choose any combination of the following activities:
  - Walking
  - Jogging
  - Lower extremity ergometry
  - Upper extremity ergometry
  - Rowing
- Intensity: 5-6 on a 0-10 Borg rating of perceived exertion scale for shortness of breath

Education sessions are offered occasionally during the year