

ASSESSING THE USE OF THE STEEP RAMP TEST IN CHRONIC OBSTRUCTIVE
PULMONARY DISEASE

A Thesis Submitted to the College of

Graduate Studies and Research

In Partial Fulfillment of the Requirements

For the Degree of Masters of Science in Health Sciences

In the College of Medicine

University of Saskatchewan

Saskatoon

By

Robyn Lorraine Chura

Permission to Use

In presenting this thesis in partial fulfilment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Requests for permission to copy or to make other use of material in this thesis in whole or part should be addressed to:

Dean of the College of Medicine
University of Saskatchewan
Saskatoon, Saskatchewan S7N 5E5

ABSTRACT

ASSESSING THE USE OF THE STEEP RAMP TEST IN CHRONIC OBSTRUCTIVE PULMONARY DISEASE

The purpose of this study was to compare power output and ventilatory measurements between the steep ramp test (SR) and both the 30-second Wingate anaerobic (WAT) and standard cardiopulmonary exercise tests (CPET) in chronic obstructive pulmonary disease (COPD). 11 patients (7 males and 4 females) underwent spirometry, a CPET, WAT and SR test. Repeated measures ANOVA was used to compare the differences between the peak work rate of the CPET ($CPET_{peak}$), SR (SR_{peak}), and the average power of the WAT (W_{avg}). The W_{avg} was higher than the SR_{peak} , which was higher than the CPET (231.2 ± 113.4 , 156.8 ± 67.9 , 65.9 ± 35.9 , $p < 0.05$ respectively). There were no differences found between the tests at end-exercise for inspiratory reserve volume (IRV), ventilation (V_E), and end-expiratory lung volume (EELV). Tidal volume (V_T) was also compared between the tests as a percentage of the inspiratory capacity (IC) remaining at end-exercise and no differences were found. The similarity between the ventilatory measures indicates a similar level of constraint, despite the large difference in work rates achieved, in all 3 tests. This shows that a standard CPET underestimates leg power in COPD patients, and the WAT and SR may be better indicators of leg muscle power and anaerobic type exercise.

ACKNOWLEDGMENTS

I would like to thank a number of people who assisted me in the completion of this thesis. My co-supervisors, Dr. Darcy Marciniuk and Dr. Scott Butcher, patiently answered my plethora of questions and Dr. Butcher's mentorship in all aspects of academia and research was very much appreciated. Dr. Marciniuk and Dr. Butcher ensured my learning experience was both challenging and enjoyable and I was grateful for their incredible expertise and support. Mr. Ron Clemens' expertise in all technical aspects of running the pulmonary research lab was vital and I am thankful for the training and advice I received to use that equipment. I would also like to thank my advisory committee, Dr. Suzanne Sheppard, Dr. Don Cockcroft, and Dr. Jon Farthing, for their input and support throughout this entire process. I am thankful to Mr. Trent Litzenberger and the pulmonary rehabilitation program for allowing me to attend the program to gain more insight into COPD as a disease, as well as the difficulties these patients experience during exercise and everyday life. I would like to thank the Lung Association for helping to fund this research. I could not have done this without their support. And lastly, I am very thankful to the research subjects for their participation and tireless effort to perform to the best of their ability. They are helping to build the future of COPD rehabilitation and treatment.

TABLE OF CONTENTS

	<u>page</u>
<u>ABSTRACT.....</u>	<u>ii</u>
<u>ACKNOWLEDGMENTS</u>	<u>iii</u>
<u>LIST OF TABLES</u>	<u>6</u>
<u>LIST OF FIGURES</u>	<u>7</u>
<u>ABBREVIATIONS</u>	<u>7</u>
<u>BACKGROUND</u>	<u>10</u>
1.1 INTRODUCTION	10
1.2 REVIEW OF LITERATURE	11
1.2.1 Current Recommendations.....	11
1.2.2 Physiological Limitations	16
1.2.3 Activities of Daily Living and COPD.....	23
1.2.4 Anaerobic Training.....	25
1.2.5 Anaerobic Testing.....	28
1.2.6 Summary.....	32
1.3 PROBLEMS AND HYPOTHESES	34
1.3.1 Objectives	34
1.3.2 Hypotheses.....	34
1.3.3 Assumptions.....	34
1.3.4 Limitations	35
<u>METHODS</u>	<u>36</u>
2.1 SUBJECTS.....	36
2.1.1 Inclusion Criteria	36
2.1.2 Exclusion Criteria	38
2.2 RESEARCH DESIGN	38
2.3 PROCEDURES.....	39
2.3.1 Pulmonary Function Testing.....	39
2.3.2 Maximal Incremental Cardiopulmonary Exercise Test	39
2.3.3 30 Second Wingate Anaerobic Test.....	40
2.3.4 The Steep Ramp Test.....	42
2.3.5 Between Test Protocol	42
2.4 MEASURES	42
2.4.1 Inspiratory capacity.....	42
2.4.2 Oxygen saturation	44
2.4.3 Heart rate and rhythm	44
2.4.4 Blood pressure	44

2.4.5 Subjective symptoms	45
2.4.6 Ventilation During Exercise	45
2.5 STATISTICAL ANALYSIS.....	45
<u>RESULTS AND DISCUSSION.....</u>	<u>48</u>
3.1 RESULTS	48
3.1.1 Analysis.....	48
3.1.2 Power Analysis	50
3.2 DISCUSSION	55
3.2.1 Introduction.....	55
3.2.2 Peak work rate.....	55
3.2.3 Limitation of ventilation	57
3.2.4 Metabolic outcomes	59
3.2.5 Limitations	61
<u>CONCLUSIONS.....</u>	<u>62</u>
4.1 SUMMARY	62
4.2 CONCLUSIONS.....	63
<u>REFERENCES</u>	<u>65</u>
<u>APPENDIX 1: CONSENT FORM.....</u>	<u>71</u>
<u>APPENDIX 2: PULMONARY REHABILITATION SCHEDULE</u>	<u>72</u>

LIST OF TABLES

<u>Table</u>	<u>page</u>
1.1. Aerobic Exercise Prescription Guidelines for COPD	13
1.3. Strength Training Prescription Guidelines for COPD	15
2.1. Subject Characteristics.....	37
3.1. End Exercise Measures for the CPET, SR and WAT Presented with Means and Standard Deviations	51
3.2. Correlations of Work Rates Recorded Over 2 Sessions Presented with Means and Standard Deviations	54

LIST OF FIGURES

<u>Figure</u>	<u>page</u>
1.1. Ventilation During Exercise, with and without COPD.....	18
1.2. Canadian Respiratory Guidelines Linking Dyspnea, Stages of Disease and Disability.....	22
1.3. Canadian Respiratory Guidelines Classification of Disease Severity Based on Impairment of Lung Function.....	22
1.4. Work Rates vs. Time for CPET, WAT and SR Tests.....	33
2.1. Diagram of Lung Volumes	43
2.2. 0-10 Modified Borg Scale.....	46
3.1. Graph of Work Rates (Watts) Presented with Means and Standard Deviations.....	49
3.2. Bland-Altman Plot of Reliability of Wingate Average Power Measurements.....	52
3.3. Bland-Altman Plot of Reliability of Steep Ramp Peak Power Measurements.....	53

ABBREVIATIONS

ACSM	American College of Sports Medicine
ATP	Adenosine Triphosphate
ATS/ERS	American Thoracic Society / European Respiratory Society
CO ₂	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CPET	Cardiopulmonary Exercise Test
CPET _{peak}	Cardiopulmonary Exercise Test Peak Work Rate
DLCO	Diffusing Capacity of the Lung of Carbon Monoxide
ECG	Electrocardiogram
EELV	End Expiratory Lung Volume
EILV	End Inspiratory Lung Volume
FEV ₁	Volume of Forcibly Expired Air in 1 Second
FVC	Forced Vital Capacity
IC	Inspiratory Capacity
IRV	Inspiratory Reserve Volume
PCr	Phosphocreatine
PWR	Peak Work Rate
RER	Respiratory Exchange Ratio
RPE	Rating of Perceived Exertion

RR	Respiratory Rate
SpO ₂	Oxygen Saturation
SR	Steep Ramp
SR _{50%}	50% of the Steep Ramp Peak Work Rate
SR _{peak}	Steep Ramp Peak Work Rate
TLC	Total Lung Capacity
WAT	Wingate Anaerobic Test
VCO ₂	Volume of Carbon Dioxide Elimination
VCO _{2peak}	Volume of Carbon Dioxide Elimination at Peak Exercise
VO ₂	Volume of Oxygen Consumption
VO _{2MAX}	Maximal Volume of Oxygen Consumption
V _T	Tidal Volume
W _{avg}	Wingate Average Work Rate
V _E	Minute Ventilation

CHAPTER 1 BACKGROUND

1.1 INTRODUCTION

Chronic Obstructive Pulmonary Disease (COPD) is one of Canada's fastest growing chronic diseases, leading to increased mortality (Lacasse, Brooks, & Goldstein, 1999), as well as numerous complicating co-morbidities in various clinical situations (Bourbeau, Nault, & Borycki, 2002; O'Donnell et al., 2007). COPD is the current preferred term for abnormalities of the lung including chronic bronchitis and emphysema (Bourbeau et al., 2002). It is usually caused by smoking and is characterized by partially reversible airway obstruction, impaired gas exchange, lung hyperinflation, chronic cough and systemic manifestations (O'Donnell et al., 2007). Initially, the respiratory deficiencies are most prominent in COPD (O'Donnell et al., 2007); however, derangements of the skeletal muscle and cardiovascular system also typically occur in advanced disease (Butcher & Jones, 2006).

Individuals with COPD are often prescribed aerobic exercise to enhance function and reduce shortness of breath during activities of daily living. Current recommendations have progressed beyond general guidelines to suggest that exercise at higher intensities is more beneficial for this population (Casaburi et al., 1997; Coppoolse et al., 1999). Unfortunately, ventilatory limitations may not allow high intensity continuous exercise to be tolerated for long periods of time, which leads to frequent rest breaks (Puhan et al., 2006) and potentially reduced adherence to prescribed exercise. A predominance of type II muscle fibers caused by muscle myopathy (O'Donnell et al., 2007) in these patients also may not be conducive to long term aerobic activity. In addition, a pattern of very high energy demand followed by rest periods is often found during activities of daily living for these patients resulting in an increased use of anaerobic energy to accomplish

these activities (Coppoolse et al., 1999; Smodlaka & Adamovich, 1974). If enhanced daily function is the goal, it might be desirable if a similar pattern of training was reflected in the design and content of their exercise program.

Interval training is similar to the pattern of activities of daily living for COPD patients by including periods of high intensity work interspersed with periods of rest. Interval training has not traditionally been used in this population and there is a lack of consensus in regards to prescription guidelines. Interval exercise intensity may be prescribed for healthy individuals based on tests of anaerobic power and capacity, such as a Wingate Anaerobic Test (WAT), but these types of tests have not been widely used for individuals with COPD. The steep ramp (SR) test has been used repeatedly in the literature to prescribe interval training intensities for individuals with chronic heart failure (Meyer et al., 1996; Meyer, Schwaibold et al., 1996; Meyer et al., 1997), so it may also be effective for use in COPD patients because many of the peripheral skeletal muscle derangements in chronic heart failure and COPD are similar.

1.2 REVIEW OF LITERATURE

The review of the literature outlines the current recommendations for exercise prescription, the physiological limitations in COPD which make it difficult for these patients to exercise and perform activities of daily living, and some emerging research trends that suggest that high intensity interval training may be beneficial in COPD.

1.2.1 Current Recommendations

Aerobic exercise training has long been known to improve the health status and quality of life of individuals with COPD (Durstine & Moore, 2003). Significant and clinically meaningful improvements in exercise tolerance (O'Donnell et al., 2007; Ries et al., 2007), decreased dyspnea (Balady et al., 2000; Ries et al., 2007) and a reduction in dynamic hyperinflation (Porszasz et al., 2005) have been observed through exercise training. Exercise prescription varies slightly

depending on the goals and abilities of the individual. Table 1.1 illustrates the suggested prescription for aerobic and strength training for individuals with COPD based on American College of Sports Medicine (ACSM) guidelines (Durstine & Moore, 2003); however, a further understanding of the guidelines is necessary in order to adjust and optimize prescription for each individual.

The ACSM recommendations for aerobic exercise training for individuals with COPD are limited to submaximal training factors that focus on duration rather than intensity. As when prescribing exercise in the normal population, a focus on large muscle activities is desirable for an aerobic response (Balady et al., 2000). Walking and cycling are straightforward exercises for COPD patients, and they may be easily monitored under appropriate supervision in a clinical setting. The frequency of exercise sessions should be 3-7 days per week depending whether the desired results are for maintenance or for a training effect. A goal of 30 minutes of sustained exercise per training session is desirable, but most individuals will only initially be able to tolerate a few minutes at a time due to deconditioning and dyspnea (Durstine & Moore, 2003). Therefore, rest breaks may be taken initially, to attain relief of symptoms, in order to complete a continuous exercise training session (Durstine & Moore, 2003).

The intensity of exercise is prescribed differently than in normal individuals due to the ventilatory restrictions experienced in COPD (Horowitz, Littenberg, & Mahler, 1996). It may be difficult to accurately prescribe intensity with traditional measures such as heart rate reserve or a percentage of maximal oxygen consumption because many individuals reach a ventilatory mechanical limit, due in part to dynamic hyperinflation, increased dead space ventilation,

Table 1.1. Aerobic exercise guidelines for COPD

Mode	Frequency	Intensity	Duration
Aerobic walking or cycling	3-7 days/wk	RPE 11-13/20 Dyspnea scale 5/10	Goal: 30 mins (shorter sessions may be necessary initially) Emphasize increasing duration>intensity

RPE = Rate of perceived exertion. Adapted from ACSM's exercise management for persons with chronic diseases and disabilities, 2nd ed (Durstine & Moore, 2003).

increased work of breathing, and impaired gas exchange before they are able to reach a true cardiovascular limit (Butcher & Jones, 2006; Horowitz et al., 1996).

It is acceptable to monitor subjective intensity and symptoms using ratings of perceived exertion (RPE) and/or a dyspnea rating scale. It has been demonstrated that individuals with COPD are able to reproduce a desired intensity using a dyspnea target of 5/10 (“severe”) during 10 minutes of submaximal exercise (Horowitz et al., 1996). By increasing exercise endurance through aerobic training, individuals experience increased quality of life and positive physiological responses (O'Donnell et al., 2007).

More recent research has suggested that higher intensity continuous training is more beneficial for COPD patients (Casaburi et al., 1997; Coppoolse et al., 1999) and that 60% of peak work rate (PWR) is sufficient for producing a training response (Coppoolse et al., 1999). In recognizing the need to exercise above anaerobic threshold to induce a training response, the American Thoracic Society and European Respiratory Society have updated their guidelines to suggest continuous aerobic exercise at >60% PWR for >30 minutes, >3 times per week may be beneficial (Nici et al., 2006).

Resistance training is an important component of pulmonary rehabilitation in order to increase muscle strength and mass, which may make activities of daily living easier. Table 1.2 displays the ACSM guidelines for strength training for this population (Durstine & Moore, 2003). The ACSM focuses on high repetitions and low resistance, which follows their recommendations to concentrate on endurance rather than intensity for this population. Similar to the recent research outlined above regarding higher intensity aerobic training, it may be beneficial in some cases to increase resistance and reduce repetitions in order to maintain a training effect while decreasing dyspnea. It has been shown in elderly male COPD patients that

Table 1.2. Strength training guidelines for COPD

Mode	Frequency	Intensity
Strength Free weights or machines	2-3 days/wk	Low resistance, high reps Goal: increase number of reps

Adapted from ACSM's exercise management for persons with chronic diseases and disabilities, 2nd ed (Durstine & Moore, 2003).

heavy resistance training twice a week produced significant improvements in strength and was tolerated well by the participants (Kongsgaard, Backer, Jorgensen, Kjaer, & Beyer, 2004). The American Thoracic Society and European Respiratory Society (ATS/ERS) recommendations seem to find a balance between conservative prescription and this recent research to suggest that strength training include 2-4 sets of 6-12 repetitions at an intensity of 50-85% of a one repetition maximum (Nici et al., 2006). However, it is prudent to start any exercise program at a lower intensity, as with normal subjects, in order to ensure proper technique, reduce the likelihood of muscle soreness, and promote adherence to exercise.

1.2.2 Physiological Limitations

The physiological limitations to exercise experienced by individuals with COPD, and the reasons behind them, may not be immediately obvious to those prescribing or monitoring exercise in this population. There are factors of the disease itself that are not fully understood but seem to have an impact on exercise and activities of daily living. Some physiological limitations to exercise are outlined below. COPD patients may or may not exhibit all of these limitations to exercise depending on the severity and course of their disease.

1.2.2.1 Ventilation

There are multiple factors that contribute to exercise limitations in COPD patients, but limited ventilation is one of the primary issues (O'Donnell, Revill, & Webb, 2001; O'Donnell & Webb, 2008). Lung function becomes compromised when pathological processes begin to take place in the lung tissue. Lung tissue destruction caused by inflammatory processes results in decreased tissue elastin and small airway collapse (O'Donnell et al., 2007). The result of these processes is airway closure and distal air trapping that occurs primarily during expiration (Bourbeau et al., 2002). The decreased elastic recoil of the lungs results in a reduced driving

force during expiration, which is unable to maintain patency of the small airways and limits expiratory flow rates (Bourbeau et al., 2002; O'Donnell et al., 2007). This expiratory flow limitation is the hallmark of the disease (O'Donnell et al., 2007). Gas exchange abnormalities are also common, and many individuals experience hypoxemia and respiratory acidosis from the retained carbon dioxide (CO₂) (West, 2003).

Airway obstruction can cause air trapping which becomes more prominent during exercise, or some activities of daily living, where an increase in tidal volume (V_T) and respiratory rate (RR) is necessary to cope with increasing physiological demands (Butcher & Jones, 2006; Vogiatzis et al., 2004). However, due to the expiratory flow limitation, they are unable to completely exhale before needing to take another breath. The individual continues to inhale more than they exhale and this causes dynamic hyperinflation (O'Donnell et al., 2001; O'Donnell & Webb, 2008) and a rapid shallow breathing pattern. A number of consequences take place as more air trapping occurs: end-expiratory lung volume (EELV) increases, inspiratory reserve volume (IRV) is markedly reduced, and V_T approaches the upper limits of total lung capacity (TLC) (See Figure 1.1) (Butcher & Jones, 2006; Porszasz et al., 2005; Vogiatzis et al., 2004; Vogiatzis et al., 2005). Added to this is the physiological strain of the respiratory muscles working in a shortened position due to the hyperinflation of the lungs (Porszasz et al., 2005). The increased work of breathing adds to the negative consequences experienced by the patient due to their rapid, shallow breathing pattern. This cycle causes the individual with COPD to become short of breath, activity limited, and exhausted very quickly with minimal activity.

Many individuals with COPD do not reach a maximal heart rate or maximal rate of oxygen consumption (VO_{2max}) during a maximal incremental exercise test due to the early onset

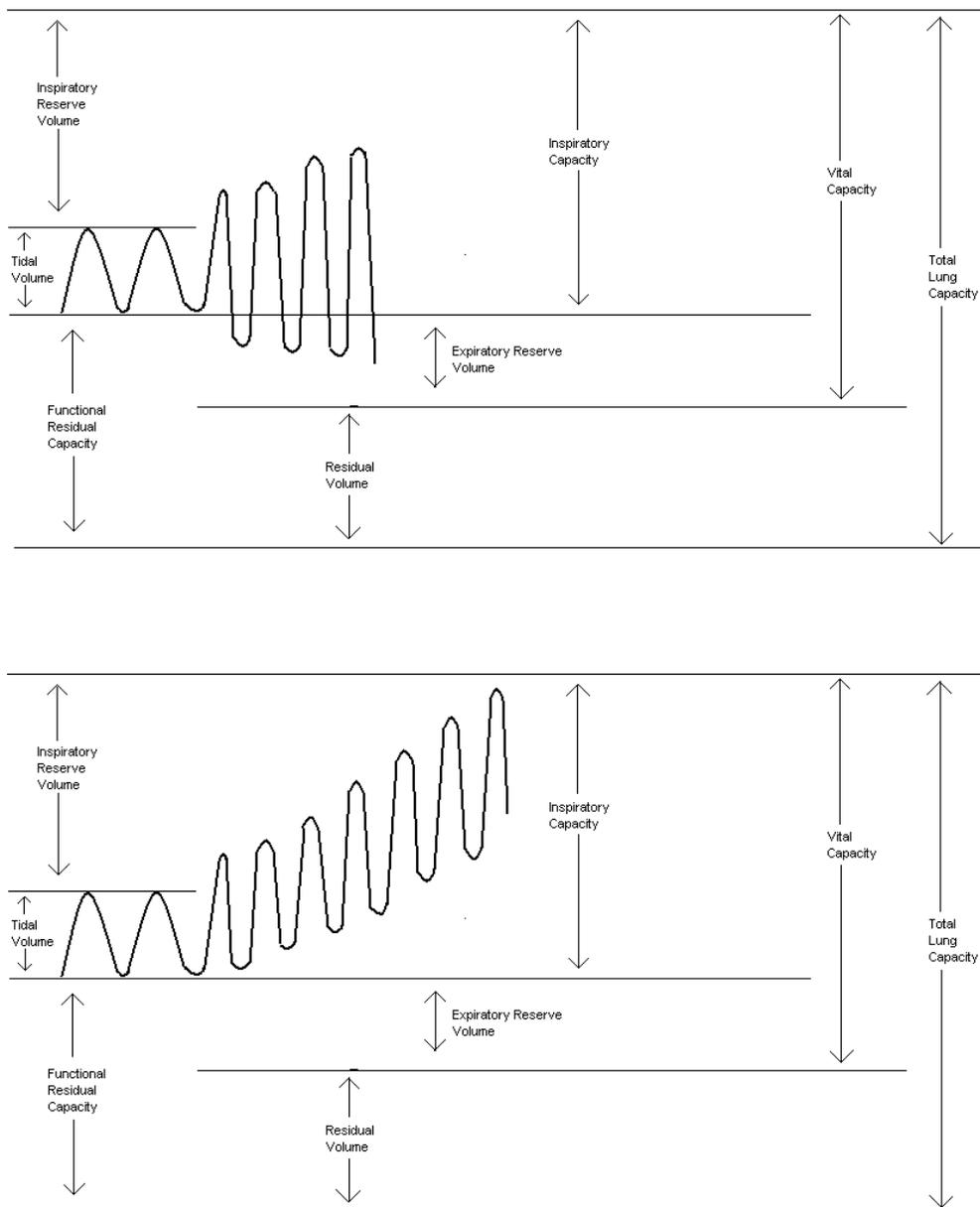


Figure 1.1. Ventilation during exercise in an individual without COPD (top) and with COPD (bottom). Normal increases in respiratory rate and tidal volume also result in increased inspiratory capacity in the individual without COPD. In COPD, dynamic hyperinflation is associated with exercise lung volume and reduced inspiratory capacity.

of dynamic hyperinflation (Butcher & Jones, 2006; Vogiatzis et al., 2004; Vogiatzis et al., 2005). Therefore, the common practice of prescribing exercise as a percentage of VO_{2max} , PWR or peak heart rate should not be used because the work rate prescribed will likely underestimate the patient's true capabilities (Butcher & Jones, 2006; Meyer et al., 1996).

1.2.2.2 Muscle Dysfunction

For many patients, especially in milder cases of COPD, leg fatigue is the limiting factor to exercise (A. Aliverti & Macklem, 2001; Butcher, 2008). Although the patient may complain of muscle fatigue, it is likely that lack of oxygen delivery to the peripheral muscles is a contributor in their exercise limitation (A. Aliverti & Macklem, 2008). Lung obstruction and dynamic hyperinflation causes the respiratory muscles to be demanding of oxygen at the expense of other peripheral muscles. The respiratory muscles may use up to 55% of the available oxygen supply, robbing the locomotor muscles of much needed oxygen for continued function during exercise (A. Aliverti & Macklem, 2008). Peripheral muscle dysfunction may also be caused by chronic disuse of muscles, decreased fat free mass and altered fiber type (Jagoe & Engelen, 2003). Although these physiological findings related to muscle dysfunction are not fully understood, there are COPD related factors that may play a role in their origin (Jagoe & Engelen, 2003).

COPD patients often have a reduced muscle mass, or fat free mass, as a result of muscle wasting (O'Donnell et al., 2007). This wasting may be caused by disuse, which not only causes atrophy of the muscle itself but also causes a shift in the ratio of fiber type from fewer oxidative type I fibers to more glycolytic fast twitch type II fibers (Jagoe & Engelen, 2003). Gosker et al (Gosker, Hesselink, Duimel, Ward, & Schols, A M W J., 2007) found that the decreased oxidative capacity of the vastus lateralis in individuals with COPD is due to fewer mitochondria, which may be a result of fewer type I fibers (Gosker et al., 2007). They also found that the

tibialis anterior muscle retained the proper mitochondrial ratio compared to normal individuals. It was postulated that since the tibialis muscle was required for almost constant postural activities, it was necessary to have more type I fibers (Gosker et al., 2007). It is known that rest, disuse, or a reduction in activity, promotes a shift toward type II fibers (Harridge, 2007) and it may be the subjects in that study did not use their quadriceps muscles as extensively as the tibialis muscle on a day to day basis. Exercise training helps to reduce the undesirable fiber type ratio in the vastus lateralis, or other peripheral muscles, toward a more favorable ratio of increased oxidative type I fibers used for prolonged activities (Harridge, 2007).

Poor nutrition is a factor which may contribute to decreased muscle mass through reduced protein synthesis. Decreased caloric intake or increased energy expenditure are believed to be partially to blame for muscle wasting (Jago & Engelen, 2003) but increasing caloric intake usually results in fat mass being gained in these patients (Jago & Engelen, 2003). In addition, it may be important to examine the composition of the diet to ensure adequate protein is being consumed for protein synthesis to occur (Jago & Engelen, 2003). The decreased cross-sectional area of type I and II fibers as well as the overall reduction in cross-sectional area of the muscle found in these patients is likely the result of a general protein deficit at the cellular level (Debigare & Maltais, 2008). Even with sufficient protein available, the hypoxia observed in patients with COPD inhibits protein synthesis and may cause further proteolysis to occur through calcium-dependent proteolytic enzymes (Jago & Engelen, 2003). Respiratory acidosis, which occurs with exacerbations or is present in more severe COPD, may also amplify proteolysis (Jago & Engelen, 2003).

Although severe muscle wasting does not seem to be associated with occasional low-dose steroid use in COPD patients, muscle function may be impaired with acute high-dose or

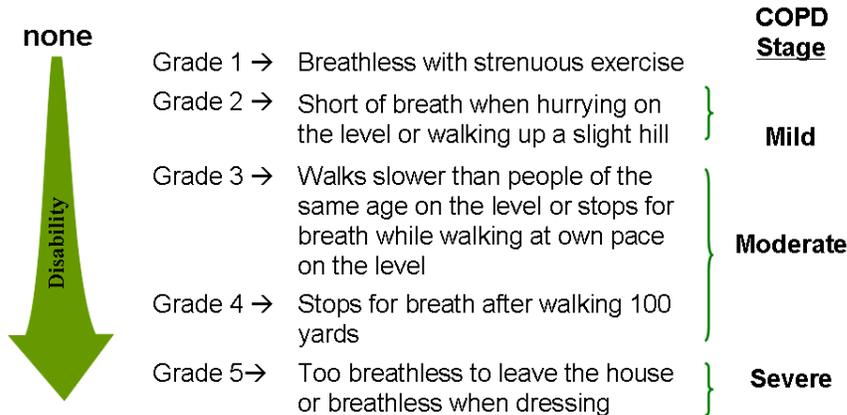
cumulative steroid use (Jagoe & Engelen, 2003; Dekhuijzen & Decramer, 1992). Cumulative moderate-dose systemic cortico-steroid use is known to cause limb muscle weakness followed by respiratory muscle involvement (Dekhuijzen & Decramer, 1992). The effects of beta-2-agonists, a staple of therapy for COPD, on protein synthesis, muscle dysfunction, and ultimately exercise outcomes are not well understood (Jagoe & Engelen, 2003).

Swallow et al (2007) found that quadriceps strength was a better indicator of mortality than ventilatory status in COPD patients. To the best of my knowledge, it is unknown whether quadriceps strength is a causative factor of mortality or whether it is a marker of disease severity which also leads to mortality. In the absence of such data, it is important to consider that it may be a causative factor that can be influenced by exercise training which would lead to a decreased risk of early mortality. It may therefore be a disservice to COPD patients to solely counsel them to exercise aerobically without emphasizing the importance of muscle strength as well.

Although COPD is classified as a lung disease, peripheral muscle dysfunction is present, and must be recognized as a multifactorial contributor to the disability patients experience. The Canadian Thoracic Society recognizes the multiple issues affecting COPD patients and has reflected that in the classification guidelines (O'Donnell et al., 2008). The guidelines recognize a connection between symptoms, disability and lung function impairment and are presented in Figures 1.2 and 1.3. It is apparent that patients who are classified as “mild” according to their lung function impairment may find that they are classified as “moderate” according to their symptoms.

As outlined above, a true physiologic maximum is often not achieved during incremental exercise testing causing an underestimation in the work rate that the individual can perform (Butcher & Jones, 2006). A percentage of the underestimated PWR results in an intensity that

Assessing Disability in COPD – MRC Dyspnea Scale



Can Respir J 2008;15(Suppl A):1A-8A.

Figure 1.2. Canadian respiratory guidelines linking dyspnea, stages of disease and disability. Canadian Thoracic Society 2008 Powerpoint slide update kit (*Canadian thoracic society - guidelines & standards.*)

Classification by Impairment of Lung Function*

Stage	Spirometry (post-bronchodilator)
Mild	FEV ₁ ≥ 80% predicted, FEV ₁ /FVC < 0.7
Moderate	FEV ₁ 50 – 79% predicted, FEV ₁ /FVC < 0.7
Severe	FEV ₁ 30 – 49% predicted, FEV ₁ /FVC < 0.7
Very Severe	FEV ₁ < 30% predicted, FEV ₁ /FVC < 0.7

**In keeping with current GOLD guidelines classification system*

Can Respir J 2008;15(Suppl A):1A-8A.

Figure 1.3. Canadian respiratory guidelines classification of disease severity based on impairment of lung function. Canadian Thoracic Society 2008 Powerpoint slide update kit (*Canadian thoracic society - guidelines & standards.*)

contributes to dynamic hyperinflation but does not challenge the peripheral muscles and thus, minimizes potential strength gains and perhaps adds to the cycle of disuse and atrophy. The under usage of peripheral muscles may lead to a high glycolytic to oxidative fiber type and enzyme ratio which further undermines the individual's ability to perform endurance activity. Even if strength training is used to address the specific muscle weakness and myopathy that is present, a proper amount of protein and calories must be consumed in the diet to overcome the muscle wasting that occurs with cumulative steroid use (Jagoe & Engelen, 2003).

It is obvious that the myopathy and cycle of disuse is a result of a myriad of factors acting positively or negatively on muscle physiology. The goal of exercise is to assist in achieving a positive balance of muscle protein synthesis and overall exercise capacity in order to help the individual become less symptomatic and more proficient with activities of daily living.

1.2.3 Activities of Daily Living and COPD

COPD patients are often diagnosed after they have noticed increasing shortness of breath with activities that were previously done with ease. These individuals appear to be able to perform activities of daily living that only require a low energy cost such as cooking, slow walking or light housework; however, other activities such as climbing stairs or walking briskly are often too difficult (Butcher & Jones, 2006). Velloso et al (2003) studied the physiological cost of COPD patients and controls performing 4 upper limb activities. The groups were not compared except to comment regarding reliability of the testing. The researchers found that the COPD patients did the activities at a significantly higher volume of consumed oxygen (VO_2) (50.2% mean of VO_{2max}) and ventilation (V_E) (mean 55.7% of max voluntary ventilation) in relation to resting measurements, which the researchers thought likely explains the exhaustion COPD patients experience during activities of daily living (Velloso et al., 2003). The energy cost was higher in the COPD patients and they would likely be unable to sustain those activities

for a long period of time without frequent rest breaks (Yquel et al., 2006). There seems to be some activities of daily living that require a lower level of energy and others that require a higher level of functioning (Yquel et al., 2006). Perrault (2006) found that the efficiency of the skeletal muscles to perform movement varies with the activity that is being performed. Furthermore, individuals with COPD tend to have a greater energy demand and waste energy physiologically through a higher cost for ventilation and a reduced efficiency of muscle due to increased type II to type I fiber ratio (Perrault, 2006).

At the onset of submaximal exercise, the phosphocreatine (PCr) and lactate anaerobic systems provide the energy necessary for the working muscles until the aerobic system is functioning well enough to replenish the adenosine triphosphate (ATP) for continued work (American College of Sports Medicine, 2006). The oxygen debt must be overcome by aerobic metabolism in order to reach a steady state. VO_2 kinetics describes how quickly one is able to shift to aerobic metabolism and reduce the amount of initial muscle fatigue that occurs with the onset of exercise. COPD patients have slower VO_2 kinetics compared to age-matched controls (Casaburi et al., 1997) and this may be a reflection of the decreased number of type I fibers seen in the muscles. With fewer type I fibers, there are fewer mitochondria available to contribute to aerobic metabolism and these patients have a prolonged anaerobic contribution to metabolism for a longer period of time than normal individuals. Therefore, activities of daily living that may be low in intensity may still be largely anaerobic in individuals with COPD.

Many of the changes in muscle physiology are also seen in chronic heart failure patients (Meyer et al., 1996) who also tend to have similar difficulties with activities of daily living that require both endurance and short bursts of energy (Meyer et al., 1996). Individuals with COPD or chronic heart failure, depending on the severity of their disease, may be able to sustain low

energy activities for a longer period of time but find difficulty sustaining moderate or high energy activities without resting for short periods during the activity (Smodlaka & Adamovich, 1974). For example, those individuals will report that they may be able to walk slowly on the level for a long period of time, but are only able to climb stairs by taking rest breaks. For patients with more severe disease, most of their daily activities must be completed by using rest breaks (Smodlaka & Adamovich, 1974). For these individuals, their activity pattern closely resembles an anaerobic pattern of performing an activity for 1-2 minutes and then resting (Coppoolse et al., 1999). They continually reinforce a short term, high energy expenditure pattern interrupted by periods of rest (Butcher & Jones, 2006; Coppoolse et al., 1999). Therefore, as training should be specific to the desired outcome, it appears important to train the anaerobic system using high work rate intervals to help these patients become more efficient with tasks of everyday living.

1.2.4 Anaerobic Training

Continuous exercise has been shown to increase PWR (Arnardóttir, Boman, Larsson, Hedenström, & Emtner, 2007; Vogiatzis et al., 2002), endurance time (Punzal, Ries, Kaplan, & Prewitt, 1991), VO_{2max} (Arnardóttir et al., 2007; Coppoolse et al., 1999; Punzal et al., 1991), lactate threshold (Vogiatzis et al., 2002), capillary to muscle fiber ratio (Vogiatzis et al., 2005), and cross sectional area of muscle fibers (Vogiatzis et al., 2005) while decreasing symptoms (Punzal et al., 1991; Vogiatzis et al., 2002). Unfortunately, ventilatory limitations often limit the intensity or amount of muscle activity that is sufficient to induce an increase in muscle mass or a shift to slow twitch fibers (Jagoe & Engelen, 2003).

High intensity continuous training has been shown to be beneficial by Casaburi et al (1991) in their study comparing continuous exercise at intensities of 50% and 80% PWR in COPD patients with moderate disease. Higher intensity may be associated with greater benefit of

training (Casaburi et al., 1991) but it is difficult to encourage patients to exercise at a high workload when they experience symptoms of dyspnea. Maltais et al (Maltais et al., 1997) found that individuals with severe disease could not maintain continuous exercise at 80% PWR. With these high levels of intensity, it becomes necessary for some patients to take unscheduled rest breaks during the session due to dyspnea (Puhan et al., 2006). Interval training may be used to enhance fitness while allowing relief of symptoms during scheduled periods of rest or decreased intensity (Nici et al., 2006).

The recommendation by the ATS/ERS that interval training is beneficial for COPD patients is based on the results from 2 trials (Coppoolse et al., 1999; Vogiatzis et al., 2002). Coppoolse et al (1999) showed that interval training had a direct effect on increased PWR and a subjective decrease in leg pain. They also found a more pronounced increase in aerobic power in the continuous training group as shown by a higher VO_{2max} and a more significant decrease in lactic acid production during a submaximal exercise test (Coppoolse et al., 1999). Although the sample size was small, it appeared that continuous training invoked a stronger aerobic response while the interval training increased anaerobic capacity as evidenced by improved exercise tolerance to lactic acid at higher work rates (Coppoolse et al., 1999). Vogiatzis et al (2002) found similar responses but also found a decrease in dyspnea as well as leg fatigue in the interval training group. This important finding suggests that patients can improve their fitness with the same total work load using high work rate intervals with less dyspnea than continuous exercise (Vogiatzis et al., 2002). The differences in these studies may be related to study design. The Coppoolse et al study prescribed interval training interspersed with continuous training to avoid possible injury to their interval training group (Coppoolse et al., 1999). This reduced the total amount of high intensity intervals they performed over the training period compared to the

Vogiatzis et al study. Also, Coppoolse et al used 1 min high intensity interspersed with 2 min of low intensity work, rather than the 30 second work to 30 second rest ratio in the Vogiatzis et al study. This may have underestimated the differences in physiological response between continuous and interval training. The longer intervals combined with the continuous nature of the interval training protocol in Coppoolse's study may have contributed to as much dyspnea as continuous training in this population.(Vogiatzis et al., 2005)

In another study by Vogiatzis et al (2004), COPD patients were evaluated with an initial graded incremental exercise test, followed by a constant load exercise test at 80% PWR, and then interval exercise including 100% PWR for 30 seconds and unloaded pedaling for 30 seconds. IRV was significantly higher after the interval exercise than for the other 2 tests indicating a decreased amount of dynamic hyperinflation. The patients were able to exercise longer and for a higher total workload during the interval exercise than during the continuous exercise but with less lactate build-up, less hyperinflation and less pH acidity (Vogiatzis et al., 2004).

Vogiatzis et al (2005) also studied skeletal muscle changes between interval exercise and constant load exercise groups in a 10 week study. They found significant increases in capillary to fiber ratio, increases in cross sectional area of type I and IIa fibers and increased PWR in both groups. There was no significant difference in these increases between the groups, but the ratings of perceived exertion and dyspnea were lower in the interval exercise group. The interval exercise group was able to achieve the same physiological changes in the muscle with less discomfort (Vogiatzis et al., 2005).

In the 3 studies by Vogiatzis et al (Vogiatzis et al., 2002; Vogiatzis et al., 2004; Vogiatzis et al., 2005) outlined above, the physiological and most ventilatory responses tend to be similar between the interval and continuous training groups. Interval training has been shown to be

superior in these studies due to the fact that the patients can sustain interval exercise for longer periods of time with stable metabolic and ventilatory responses (Vogiatzis et al., 2004) and incur beneficial muscle adaptation (Vogiatzis et al., 2005) but with similar or fewer symptoms such as leg fatigue and dyspnea (Vogiatzis et al., 2002; Vogiatzis et al., 2004; Vogiatzis et al., 2005). Supporting these findings is a strong non-inferiority study in which Puhan et al (2006) examined 98 patients with severe COPD and proved that interval training was not inferior to high intensity continuous training, plus the patients experienced fewer symptoms. Some other studies found significant increases in ventilatory responses in their interval training groups and no difference in symptoms between continuous and interval training groups (Arnardóttir et al., 2007; Gimenez, 2000) but this may be due to the differences in methodology. Vogiatzis et al use 30 second intervals in the 3 studies cited above (Vogiatzis et al., 2002; Vogiatzis et al., 2004; Vogiatzis et al., 2005) and Puhan et al (2006) used a work-rest ratio of 20s:40s, as opposed to 1-3 minutes high intensity and 3-4 minutes low intensity as found in some other studies (Arnardóttir et al., 2007; Gimenez, 2000). The increased length of high intensity intervals may appear to increase the aerobic response like that seen in high intensity continuous exercise, but it also increases the dyspnea experienced by the patient. While high intensity training appears to be more beneficial for individuals with COPD, anxiety and dyspnea may be overwhelming to the beginner. It is important to note that training at lower intensities may be necessary to ensure compliance (Nici et al., 2006). It may be more important to have the patient subscribe fully to the rehabilitation program than to be rigid about training intensities or protocols at the expense of participation.

1.2.5 Anaerobic Testing

If interval exercise is used to stress anaerobic pathways and further enhance skeletal muscle adaptation, perhaps exercise testing should be more specific to these goals. Most studies prescribe interval intensities based on the results of a traditional graded exercise testing which, as

discussed previously, may underestimate the intensity that is attainable by this population.

Anaerobic testing has not been performed extensively in this patient population; therefore, this section will focus on the 30 second WAT, which is a valid and reliable test of anaerobic power in the healthy population, as well as anaerobic testing in chronic heart failure patients and COPD patients. Since chronic heart failure patients seem to have many of the same limitations as COPD patients, it seems likely that their exercise prescription and testing may also be related. It is for this reason that the research using the SR test is also outlined below.

1.2.5.1 30-Second Wingate Anaerobic Test

The 30-second WAT has been used for a number of years as an objective measurement of anaerobic power and capacity. The test is easy to administer, non-invasive, inexpensive, and it can be tailored for individuals of almost any age and fitness level (Bar-Or, 1987). It is administered by having the individual pedal as quickly as possible before the brake weight is applied to the flywheel and then they continue to pedal as hard as possible for 30 seconds. PWR, average work rate and decline of power are the primary outcomes that are evaluated with this test. The WAT is a good test of anaerobic power with a test-retest reliability of $r > 0.90$ (Bar-Or, 1987; Vandewalle, Peres, & Monod, 1987). Bar-Or (1987) reviewed a number of studies comparing the 30-second WAT with other tests in an effort to examine the reliability and validity of the 30-second WAT. It is considered a valid anaerobic test based on its comparison against several field measurements of activities that are anaerobic in nature, as well as lab tests that examine markers of anaerobic work (Bar-Or, 1987). The 30-second WAT displayed good association with sprinting, short distance swimming and the vertical jump (Bar-Or, 1987). Other laboratory tests, including physiological measurements were also compared to the 30-second WAT and displayed good correlation (Bar-Or, 1987). None of the studies that Bar-Or examined

can determine validity of the WAT on their own. However, by examining the studies together, one can see that the WAT reflects anaerobic energy utilization (Bar-Or, 1987).

Originally, the test was administered with a brake weight of 0.075 kp/kg of body weight. It was found through further research that optimal percentages of body weight for brake weight were necessary for different groups of individuals. For example, elite athletes require a heavier brake weight than a sedentary individual in order to see an optimal result from the test (Bar-Or, 1987). More recently, research has focused on finding optimal brake weights for people of different ages, genders, and clinical groups. Amir et al (2007) tested 59 year old men with the 30-second WAT with a 4 g/kg brake weight and Bonnefoy et al (1998) used 2.5 g/kg and 4.5 g/kg as brake weights in their protocol utilizing two 8 second ergometer sprints in elderly men. In a similar study, Kostka et al (1997) used 2.5 g/kg and 3.5 g/kg in their 8 second ergometer sprints in elderly women. Since the 30-second WAT has not been used extensively in COPD, it was necessary to decide upon the procedure based on the age and gender related studies discussed above. As many COPD patients are elderly, the above recommendations for brake weight may be appropriate for this study. Choosing a brake weight is difficult because the desired outcome of the test is a maximal anaerobic effort. If the brake weight is too heavy, the patient may not be able to complete the test. If the brake weight is too light, it may not effectively challenge the muscles for a maximal effort.

1.2.5.2 Steep Ramp Test

Recent studies examining exercise testing and prescription in chronic heart failure patients have yielded an interesting exercise test meant to elicit a peak power response that may be used to prescribe interval training. Meyer et al (1997) found that chronic heart failure patients could exercise at higher intensities than those found using an ordinary incremental ramp test

(12.5W/min). The researchers developed a SR incremental test designed to challenge the muscles maximally before the patients reached a cardiovascular limit. After an unloaded 2 minute warm-up, the intensity increases by 25 watts every 10 seconds until the patient cannot maintain the required speed or their maximum heart rate is attained (Meyer et al., 1996; Meyer et al., 1997). It has been shown in chronic heart failure patients that 50% of PWR on the SR test is approximately equivalent to 90-100% PWR of a normal incremental exercise test (Meyer et al., 1997). Much higher work rates were achieved with the SR test compared to the ordinary incremental ramp test, and a percentage of the PWR found in the SR test was used to prescribe intervals for training in this population (Meyer et al., 1997).

Puhan et al (2006) used the SR test to prescribe interval training intensities in a non-inferiority study comparing interval exercise to continuous high-intensity exercise in COPD patients. The individuals with COPD performed the SR test with a mean PWR of approximately 110 watts, while Meyer et al (1996) found that the chronic heart failure patients performed the SR test with a similar PWR of 144 watts. Puhan et al (2006) used the same 12.5 watt/minute ramp protocol for the CPET as Meyer et al (1996) and found that 50% of PWR on the SR test was equivalent to 90-100% PWR of the CPET in COPD patients, similar to the results using heart failure patients reported by Meyer et al. (1996). Puhan et al (2006) did not evaluate the physiological outcomes of the test itself, but rather used it as an anaerobic type of test to prescribe intensity for interval exercise.

Since many of the issues facing chronic heart failure patients and COPD patients are similar such as nutrition, muscle pathology, and ventilatory restrictions (Troosters, Gosselink, & Decramer, 2004), it may be reasonable to extrapolate results to the COPD population. Puhan et al (2006) found that COPD patients could also use the SR test with success and it could be used

to prescribe interval training. It appears to be a safe test to use for populations that become short of breath quickly during exercise because, rather than being a timed test, it is patient-limited. However, an important question remains unanswered: even though the PWR of a SR test may be used as a tool for prescribing anaerobic type exercise in chronic heart failure and COPD patients, what type of exercise metabolism does the SR test reflect?

A graphical representation of the tests are presented in Figure 1.4 which displays the slow increments of approximately 10 watts/minute of an aerobic power test (the CPET), the 25 watts/10 second increments of the SR test, and the large power drop from the initial peak power of the 30-second WAT.

1.2.6 Summary

Traditional aerobic exercise training for rehabilitation seems to be conservative in its prescription guidelines in order to respect the dyspnea that patients experience during exertion. Gradual increases in intensity have likely been the focus of training in order to prevent excessive dyspnea and hypoxia in the ventilatory limited patient. However, the low gradual work rates prescribed for training may not be sufficient to challenge lower extremity muscles. Although decreased muscle strength is multifactorial in nature, strength training helps to address this issue. Aerobic and strength training combined may not be sufficient to make maximal gains in exercise tolerance that translates into improved quality of life. Specificity of training should also be considered for rehabilitation in this patient population because activities of daily living more closely resemble an anaerobic pattern of exercise. It is difficult to determine exercise intensities for interval exercise from the results of a CPET because the PWR may be underestimated due to ventilatory limitation. The SR test has been used to prescribe interval exercise intensities in chronic heart failure patients but it is unclear what this test represents in terms of exercise metabolism and power output in COPD patients compared to aerobic and anaerobic tests. Puhan

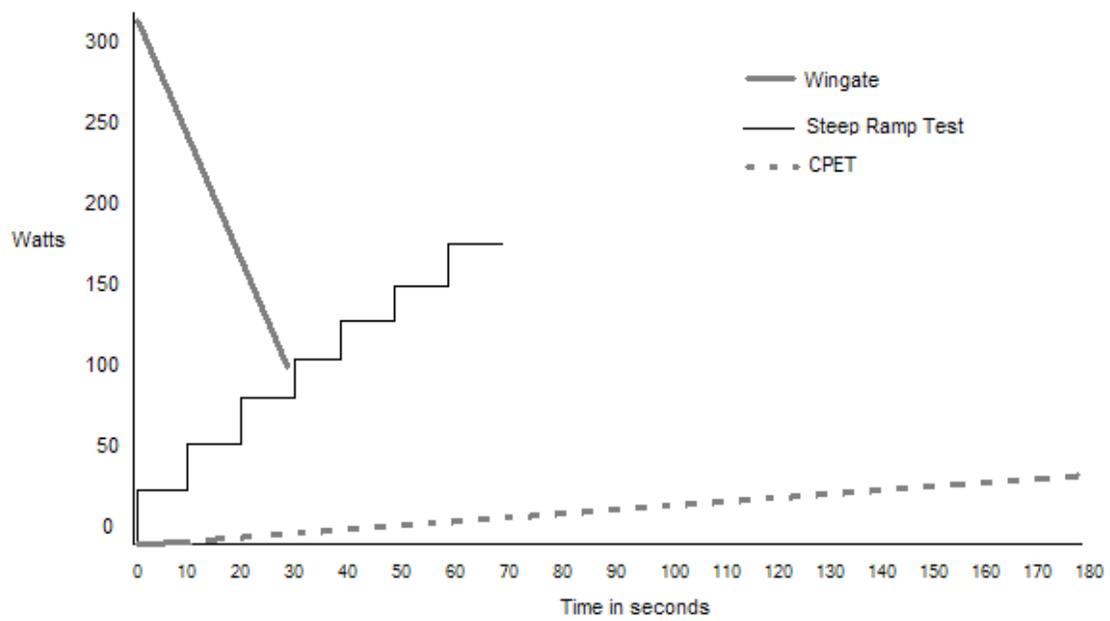


Figure 1.4. Approximate work rate (watts) achieved over time in the CPET, WAT and SR test.

used the SR test with COPD patients to prescribe interval training intensities but did not examine the physiological characteristics associated with the SR test (Puhan et al., 2006). Therefore, the purpose of this study was to compare the power output and physiological outcomes of the SR test to both an anaerobic test (the 30-second WAT) and an aerobic test, such as a CPET, in order to estimate the type of energy utilization that the SR test reflects in COPD patients. The secondary purpose was to examine the ventilatory constraint experienced in the SR test compared to the other two tests.

1.3 PROBLEMS AND HYPOTHESES

1.3.1 Objectives

1.3.1.1 Determine how the CPET, 30-second WAT and SR test compare in measuring leg power in COPD patients.

1.3.1.2 Determine what type of energy system use is reflected in the SR test.

1.3.1.3 Determine the effect of significant ventilatory constraint on the outcomes of the CPET, 30-second WAT and SR test?

1.3.2 Hypotheses

1.3.2.1 The PWR on the SR test (SR_{peak}) and the 30-second WAT average work rate (W_{avg}) will be higher than the PWR attained with the CPET ($CPET_{peak}$).

1.3.2.2 The SR test will reflect anaerobic energy utilization by correlating well with the 30-second WAT.

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.

1.3.3 Assumptions

It is assumed that the subjects will perform all tests to their maximum ability. It is also assumed that the sample represents the population being studied.

1.3.4 Limitations

This sample of fit elderly COPD patients who were familiar with regular exercise represent a small proportion of all COPD patients and may not reflect those individuals who do not exercise in a pulmonary rehabilitation program on a regular basis. This particular sample of patients also do not rely on supplemental oxygen at rest or during exercise which further narrows the ability to apply the results to a larger population. Less than maximal effort from the subjects could underestimate the outcomes of the tests. Small errors in recording mechanical, metabolic and ventilatory variables may affect results. Small sample size decreases power and may restrict evaluation of the results stratified into gender and severity of disease.

CHAPTER 2 METHODS

2.1 SUBJECTS

12 patients (8 males and 4 females) with COPD were recruited through the Saskatoon Pulmonary Rehabilitation Program and through the Division of Respiriology, Critical Care and Sleep Medicine, University of Saskatchewan. One patient was excluded because the inclusion criteria for impairment of lung function of $FEV_1/FVC < 0.7$ was not met at the screening visit. The remaining 11 patients completed the study. The subject characteristics are presented in Table 2.1.

This research was approved by the University of Saskatchewan Biomedical Ethics Committee. All subjects signed a consent form (Appendix 1) and were advised that they could freely withdraw from the study at any time.

2.1.1 Inclusion Criteria

A previously confirmed diagnosis of COPD as defined by ATS/ERS, Canadian Thoracic Society, and GOLD spirometric classification of disease (Celli BR, MacNee W. ATS/ERS Task Force, 2004; O'Donnell et al., 2008; Rabe et al., 2007), defined as post-bronchodilator $FEV_1/FVC < 0.7$ (Figure 1.3). FEV_1/FVC is a ratio of the amount of air forcibly exhaled in one second (FEV_1) compared to the vital capacity forcibly exhaled (FVC) (O'Donnell et al., 2008). Obstructive lung disease is characterized by a decreased FEV_1 and a normal or increased FVC, which leads to a decreased FEV_1/FVC ratio (O'Donnell et al., 2008). Varying degrees of severity of COPD are classified by evaluating the FEV_1 . $FEV_1 \geq 80\%$ predicted indicates mild

Table 2.1: Subject characteristics

Subject Characteristics (n=11)	
Male:Female %	64:36
Age (years)	71 ± 3
Weight (kilograms)	84.6 ± 21.0
BMI (kg/m ²)	29.3 ± 5.9
TLC (liters)	6.56 ± 1.21
FEV ₁ (% predicted)	1.08 ± 0.26 (43 ± 15)
FVC (% predicted)	2.73 ± 0.68 (83 ± 15)
FEV ₁ /FVC	41.00 ± 10.26

Abbreviations: TLC = total lung capacity, FEV₁ = forced expiratory volume in 1 second, FVC = forced vital capacity, pred = predicted.

disease, FEV₁ of 50-79% predicted indicates moderate disease, 30-49% of predicted indicates severe disease and below 30% is considered very severe disease (O'Donnell et al., 2008).

2.1.2 Exclusion Criteria

1. Acute exacerbation of COPD requiring hospital admission within the previous 6 weeks.
2. Requirement for supplemental oxygen at rest or during exercise.
3. Current known or suspected cardiac disease that would prevent patient from completing heavy exercise.
4. Use of beta blockers, which may limit or blunt the heart rate response to exercise.
5. Neuromuscular disease, stroke, vasculitis or severe arthritis, which would restrict maximal use of lower extremities.
6. Any lower extremity injury that may be exacerbated by testing, or may impair exercise responses.

2.2 RESEARCH DESIGN

A randomized cross-over design was used to test subjects' physiological responses to the 30 second WAT and the SR test. The subjects attended 3 sessions for testing, within a 3 week period, with at least 48 hours separating sessions. An initial baseline assessment session included pulmonary function tests and a CPET. The following 2 visits each included a 30 second WAT and a SR test separated by one hour. The second of these 2 visits was included in order to establish the reliability of these measures. The order of the tests was constant between visits but randomized between subjects. The subjects' order of tests was randomized in pairs in order to control for variation in the case that 1 hour between tests was insufficient for recovery. The odd numbered subjects' order of tests was randomized while the corresponding even numbered subjects' order of tests was reversed.

2.3 PROCEDURES

2.3.1 Pulmonary Function Testing

Resting pulmonary function testing was performed according to the ATS/ERS standards and guidelines (Miller MR et al., 2005; Miller MR, Hankinson J et al., 2005; Wanger J et al., 2005) using a V6200C Autobox and Vmax 229D gas analyzer manufactured by SensorMedics Corp., Yorba Linda, California, USA. Measures obtained included FEV₁, FVC, inspiratory capacity (IC), V_T, V_E, RR, and TLC. FEV₁ and FVC are necessary for classifying impairment of lung function, and TLC and IC is used to compute EELV, IRV and end-inspiratory lung volume (EILV). Diffusing capacity of the lung for carbon monoxide (DLCO) was not measured due to technical issues with the measurement system.

2.3.2 Maximal Incremental Cardiopulmonary Exercise Test

The CPET or VO_{2max} test, is an incremental test performed on a cycle ergometer that measures the maximum amount of oxygen consumption, or aerobic capacity (American College of Sports Medicine, 2006; American Thoracic Society & American College of Chest,Physicians, 2003). The test is considered physiologically maximal if any of the following occur: maximal heart rate is achieved, a plateau in oxygen uptake is observed, respiratory exchange ratio (RER) > 1.15, and the patient states that they believed it was a maximal test (American College of Sports Medicine, 2006; American Thoracic Society & American College of Chest,Physicians, 2003). Often patients with COPD do not reach maximum according to these guidelines because their ventilatory limitation stunts the progression toward a maximal heart rate and oxygen uptake response. The test still provides useful information regarding the patient's response to exercise and their ventilatory limitation.

The CPET was performed on a mechanically braked cycle ergometer (800S, SensorMedics) and physiological measurements were obtained using the gas analyzer (Vmax 229D,

SensorMedics). The intensity of the increments (5-20 watts per minute) was set by the supervisor according to experience and the patient history in order to illicit an exercise duration of 6-8 minutes (American Thoracic & American College of Chest,Physicians, 2003). Blood pressure, heart rate, oxygen saturation (SpO₂), RPE for dyspnea and fatigue, and IC were recorded every 2 minutes. 3-lead ECG readings were recorded at baseline, end-exercise and at any point where the rhythm showed any abnormalities. Physiological parameters such as VO₂, VCO₂, RER, V_T, V_E, and RR were recorded on a breath by breath basis and were averaged in 10 second increments. IC was also recorded within 15 seconds of the end of exercise. The subjects were encouraged to cycle until they could not continue. The test was terminated when the subject indicated they could not carry on, or the revolutions per minute fell 10 below the required level.

Criteria for stopping an exercise test prematurely included abnormal blood pressure responses, deteriorating heart rhythm abnormalities, lightheadedness, nauseousness, chest pain, or the subject wished to stop the test.

2.3.3 30 Second Wingate Anaerobic Test

Subjects were fitted for comfort on the cycle ergometer (Monark 894 E, Ergomedic) and the test was explained in detail. The subjects completed a self paced 5 minute warm-up with no resistance applied to the flywheel in order to warm-up the lower extremity muscles without taxing the ventilatory system. The start of the test was practiced twice so that the subject was used to the procedure of attaining maximal speed within a few seconds. The brake weight applied during the practice starts was half of the brake weight used for the actual test. Precedence for practicing with different brake weights for a few seconds was found in studies by Kostka et al (1997) and Bonnefoy et al (1998) but the intensity was not specified. The practice brake had to be heavy enough to be realistic, but not so heavy as to tire the subject.

Patients were fitted with the headgear used to hold the pneumotach and were also monitored by oximeter and 3-lead ECG. Baseline resting ventilatory data, such as IC, were recorded by the Vmax software and select parameters such as HR, SpO₂, RPE, and blood pressure were recorded manually in the chart. Patients were asked to pedal as fast as they could and as soon as they reached maximal velocity, the brake weight was applied to the flywheel. Patients tried to maintain the maximal velocity for 30 seconds. Continual encouragement was given to the patient throughout the entire test. Ventilatory parameters were monitored as during the CPET using the SensorMedics analyzer as described above. Borg RPE for dyspnea and leg fatigue, and IC were recorded at end exercise.

The principal outcome for the 30-second WAT is the average power output over the entire 30 seconds of the test. The peak power is usually attained in the first few seconds and therefore, may indicate the peak power that the leg muscles may produce for a very short amount of time. In contrast, the average power may indicate the peak anaerobic power that the leg muscles may be able to sustain for more than a few seconds (Bar-Or, 1987). The peak power may be more of an indication of the capacity of the alactic anaerobic system rather than a measurement of the ability of the anaerobic system to manage work for more than 10 seconds (Bar-Or, 1987).

As outlined in the background, the brake weight used for these subjects was not the usual 75g/kg. The brake weight for females was 35g/kg (Kostka et al., 1997) and the brake weight for males was set at 45g/kg (Bonney et al., 1998) due to the decreased muscle mass, strength and cardiopulmonary ability that is often seen in this population. There was one male subject that had a brake weight calculated at 35g/kg because he had a combined issue of being overweight and had very poor ventilatory status.

2.3.4 The Steep Ramp Test

The protocol for the SR test developed by Meyer et al (1996) was replicated for this study. The test was performed using the same equipment that was used for the CPET. Ventilatory information and vitals were monitored as per the 30-second WAT. After a 2 minute unloaded warm-up, the intensity increased by 25 watts every 10 seconds. Borg RPE and IC were obtained at the beginning and end of the test. The test was terminated when the subject indicated they could no longer continue or if the revolutions per minute fell 10 below the required level. The PWR was recorded for use in the analysis.

2.3.5 Between Test Protocol

Subjects were instructed not to eat or drink anything other than water for the hour in between the WAT and SR tests. Slow walking was encouraged, and subjects were permitted to rest if they were fatigued.

2.4 MEASURES

2.4.1 Inspiratory capacity

Measuring IC during testing is an indirect way of detecting EELV and IRV and the degree of ventilatory constraint that the patient experiences. The technique of measuring inspiratory capacity during exercise has been shown in the literature to be valid and reproducible in COPD patients (Yan, Kaminski, & Sliwinski, 1997; O'Donnell, Lam, & Webb, 1998). During exercise, the patient is asked to perform a maximal inspiration following normal expiration. The flow and volume is recorded by the metabolic cart and stored in the computer with the physiological measurements for each patient. EELV can be found by subtracting the IC from TLC. The patients' IRV can also be found by subtracting V_T from the IC. These measurements are an indication of the amount of dynamic hyperinflation that occurs during exercise (See Figure 2.1).

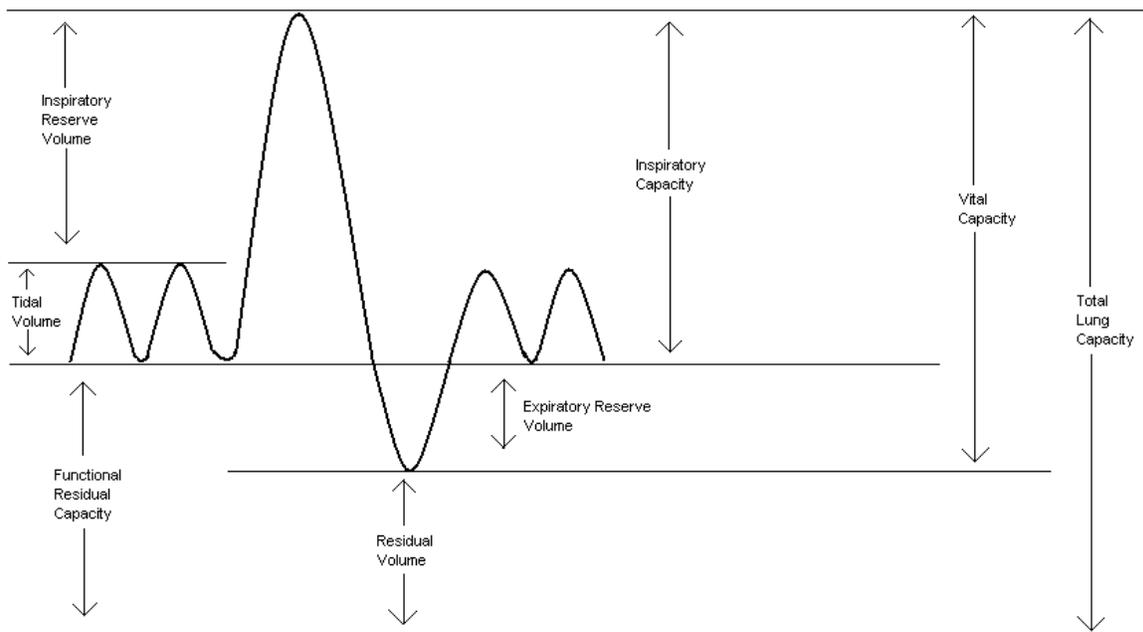


Figure 2.1. Diagram of lung volumes

V_T/IC gives the percentage of the remaining IC that is being used as V_T , which is also a measurement of ventilatory constraint (O'Donnell, Reville, & Webb, 2001).

IC was obtained at baseline, every 2 minutes during the CPET and within 15 seconds of the end of the tests. The subjects were familiarized with the examiner's cueing for IC before testing began each day.

2.4.2 Oxygen saturation

SpO₂ and heart rate were measured by a finger pulse oximeter (N-395, Nellcor). Measurements were taken at baseline, during exercise and during recovery and were recorded electronically by the metabolic cart and also manually recorded in the chart. Exercise was terminated if SpO₂ fell below 85%.

2.4.3 Heart rate and rhythm

A 3-lead electrocardiogram (ECG) was used to evaluate heart rhythm and provide confirmation of heart rate. Recordings of ECG tracings were saved electronically during baseline, recovery, and at any time during exercise when any rhythm abnormalities were noticed. Exercise was terminated if there were ischemic ECG changes, or a dysfunctional heart rhythm that was not congruent with exercise. For example, if occasional premature ventricular contractions converted to frequent couplets, trigeminy or bigeminy, the exercise test would be terminated immediately.

2.4.4 Blood pressure

Blood pressure recordings were taken manually before and after exercise testing as well as every 2 minutes during the CPET. Exercise was terminated if systolic blood pressure was >250 mm Hg, diastolic pressure was >120 mm Hg, or if there was a fall in systolic pressure >20 mm Hg from the highest value during the test.

2.4.5 Subjective symptoms

The patients were asked to report their perceptions regarding, 1) their level of dyspnea and 2) their level of leg fatigue. These 2 separate ratings of perceived exertion (RPE) were recorded using a 0-10 modified Borg scale at the beginning and at the end of each test (see Figure 2.2). RPE was also recorded every 2 minutes during the CPET. The patients were asked the same questions in the same order each time to maintain consistency: “How short of breath do you feel?” and “How tired are your legs?” The patients were unable to speak with the mouthpiece in, so they pointed to the corresponding number that matched the severity of their symptom after each of the above questions.

2.4.6 Ventilation During Exercise

Ventilation was monitored throughout all tests to determine the changes over time and end-exercise ventilatory limitations. V_T and V_E are dynamic during exercise so it is important to monitor them over time to track changes. The VO_2 and carbon dioxide elimination (VCO_2) is monitored to track changes in metabolism during exercise. The RER is the amount of CO_2 produced divided by the amount of consumed oxygen. That ratio is an estimate of what substance the body is primarily using for fuel at any given time during exercise. It can also be an indicator of exhaustion towards the end of a VO_{2max} test when the value is over 1 and is approaching 1.2 (American College of Sports Medicine, 2006).

2.5 STATISTICAL ANALYSIS

Due to the small sample size, all variables of interest were tested for normality using the Shapiro-Wilk test (Shapiro & Wilk, 1965), which is a good test of normality for samples $n < 20$. IRV% and EILV% for all 3 tests were found to be not normally distributed; therefore, examination of these variables included non-parametric analysis. The remaining variables were analyzed using parametric statistics.

10	Maximal
9	Very, very severe (almost maximal)
8	
7	Very severe
6	
5	Severe
4	Somewhat severe
3	Moderate
2	Slight
1	Very slight
0.5	Very, very slight
0	None

Figure 2.2. 0-10 Modified Borg scale used to measure subjective perceptions of both dyspnea and leg fatigue (Burdon, Juniper, Killian, Hargreave, & Campbell, 1982).

All statistical analysis was performed using a significance level of $p < 0.05$ unless otherwise stated. The analysis of the data included repeated measures analysis of variance (ANOVA) comparing the $CPET_{peak}$, SR_{peak} , and the W_{avg} . Tukey's post-hoc analysis was performed where appropriate. Pearson r correlations between the above measures were also completed to measure the strength of the relationships.

Ventilatory and metabolic results at peak exercise were also analyzed using repeated measures ANOVA. The measures that did not satisfy the assumption of normality as described previously were analyzed with Friedman's test. Reliability of the SR and the WAT was analyzed using Bland-Altman plots.

CHAPTER 3 RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 Analysis

3.1.1.1 Between test differences

The analysis revealed significant differences in work rate between the 3 tests. The CPET_{peak} was found to be lowest, followed by SR_{peak} and then W_{avg} (65.90 ± 35.90 W, 156.81 ± 67.86 W and 231.15 ± 113.36 W) (See Figure 3.1). The time to complete each of the tests was also evaluated. The CPET was the longest test, then the SR followed by the WAT (6.36 ± 2.36 min, 1.12 ± 0.45 min, 0.5 min).

The differences in physiological parameters measured in each of the tests were analyzed to determine the differences in peak exercise metabolism and ventilation. There were no significant differences found between VO₂, RR, SpO₂ or V_E measurements at peak exercise in each of the 3 tests. IC, IRV and EELV at end exercise, expressed as percentages of TLC (IC%, IRV% and EELV%, respectively), also did not show any difference. Similarly, V_T expressed as a percentage of IC (V_T/IC%) at end exercise was not significantly different between the 3 tests. VCO₂ at peak exercise (VCO_{2peak}) in the CPET was higher than VCO_{2peak} in the WAT (1.129 ± 0.522 L/min and 0.895 ± 0.422 L/min). VCO_{2peak} in the SR test (0.973 ± 0.399 L/min) was not significantly different from the other 2 tests. The RER at end exercise in the CPET (0.999 ± 0.125) was higher than both the SR and the WAT (0.898 ± 0.066 and 0.888 ± 0.079). However, the RER was not significantly different between the SR and the WAT. There was a significant

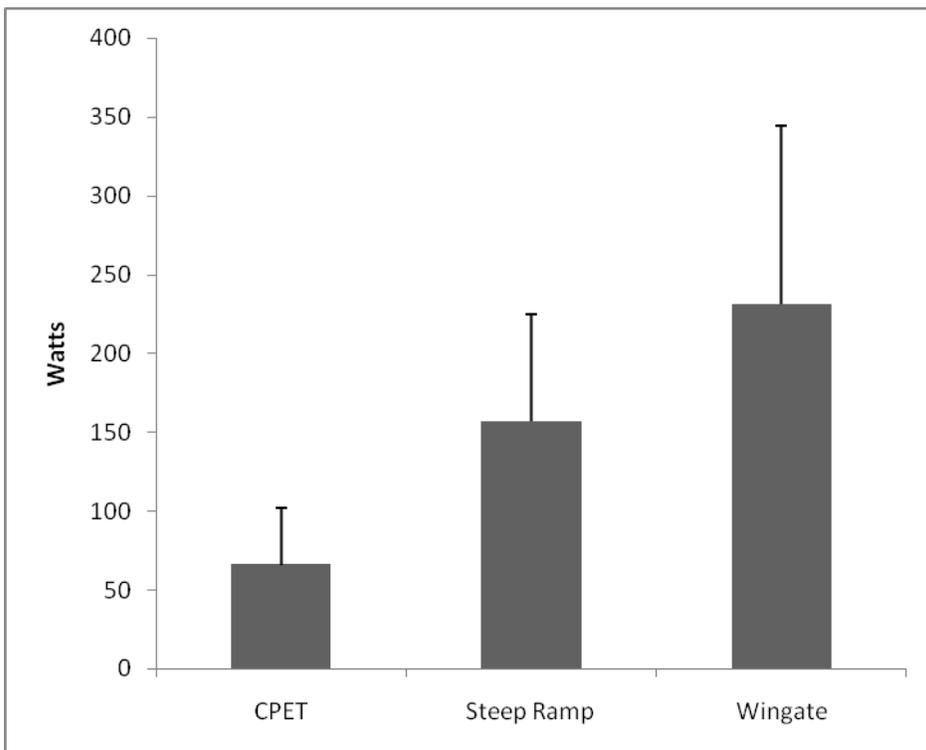


Figure 3.1: Comparison of the cardiopulmonary exercise test peak power (CPET), the steep ramp test peak power, and the average power in the 30-second Wingate anaerobic test in watts. Results are presented as mean \pm standard deviation.

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 $CPET_{\text{peak}}$ and the W_{avg} ($r = 0.887$ and 0.887 respectively). $CPET_{\text{peak}}$ 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). $V_{E\text{peak}}$ 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, VO₂=oxygen consumption, VCO₂=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, SpO₂=oxygen saturation.

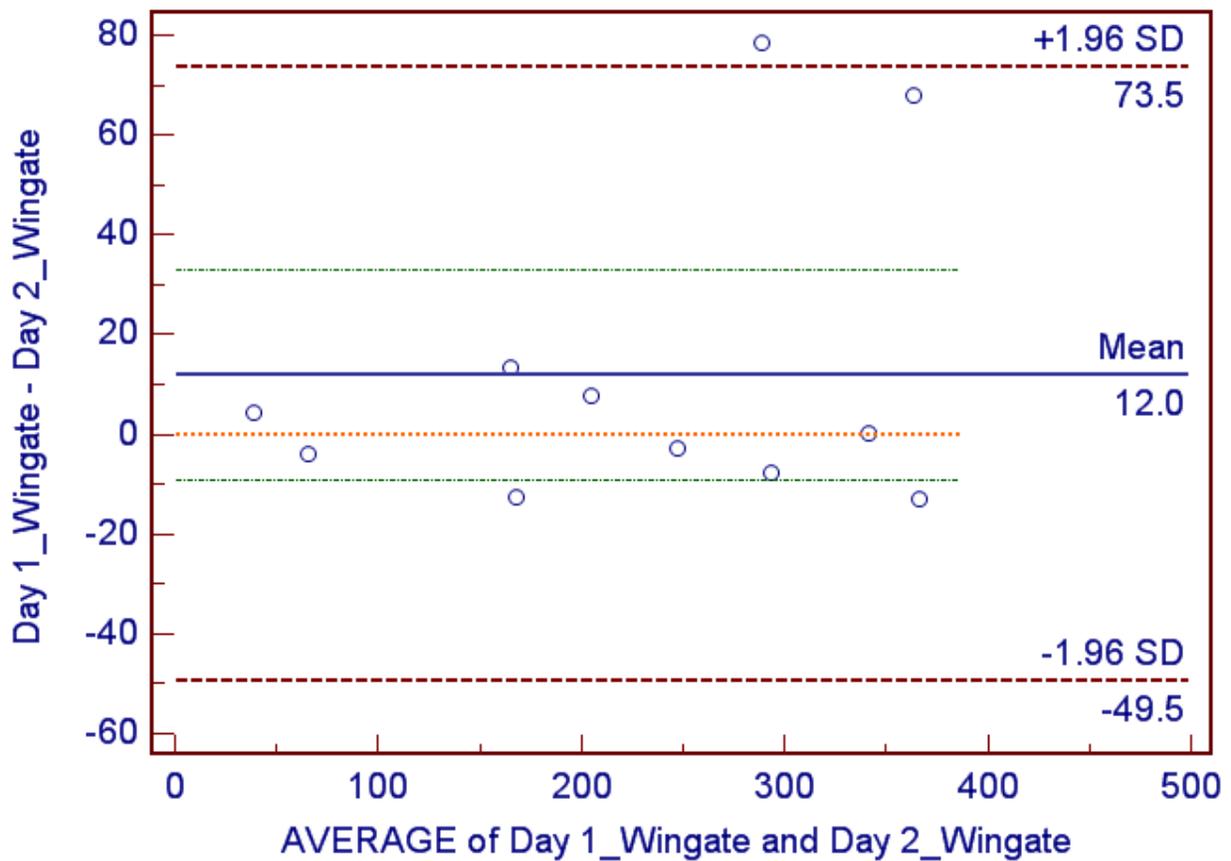


Figure 3.2. Bland-Altman plot of reliability of Wingate average power measurements (W_{avg}) between both sessions. Y-axis: The difference between W_{avg} from one day to the next. X-axis: The average of W_{avg} between both days.

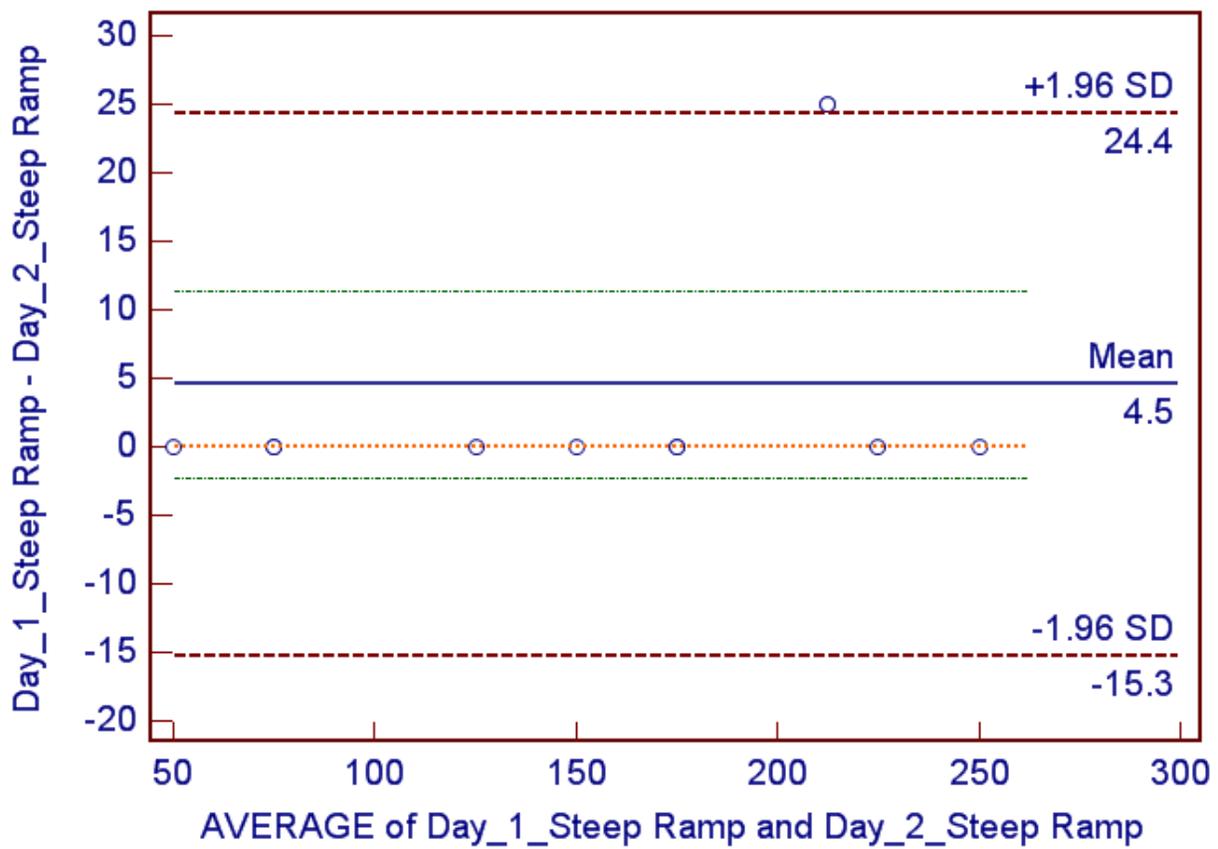


Figure 3.3. Bland-Altman plot of reliability of the steep ramp peak power measurements (SR_{peak}) between both sessions. Y-axis: The difference between SR_{peak} from one day to the next. X-axis: The average of SR_{peak} between both days.

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, Reville, & 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, Reville, & 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 ($76.47 \pm 12.98\%$ and $70.06 \pm 11.95\%$ 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 CO₂ 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 VCO_{2peak} 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 VCO_{2peak} and VO_{2peak} – 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 $CPET_{\text{peak}}$.

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.

REFERENCES

- Aliverti, A., & Macklem, P. T. (2001). How and why exercise is impaired in COPD. *Respiration*, 68(3), 229-239.
- Aliverti, A., & Macklem, P. T. (2008). Last word on point:Counterpoint: The major limitation to exercise performance in COPD is 1) inadequate energy supply to the respiratory and locomotor muscles, 2) lower limb muscle dysfunction, 3) dynamic hyperinflation. *Journal of Applied Physiology*, 105(2), 763-763.
- American College of Sports Medicine. (2006). *ACSM's advanced exercise physiology* (1st ed.) Lippincott Williams & Wilkins.
- American College of Sports Medicine. (2001). *ACSM's resource manual for guidelines for exercise testing and prescription* (4th ed.). Baltimore, Maryland: Lippincott Williams & Wilkins.
- American Thoracic Society & American College of Chest,Physicians. (2003). ATS/ACCP statement on cardiopulmonary exercise testing.[see comment][erratum appears in am J respir crit care med. 2003 may 15;1451-2]. *American Journal of Respiratory & Critical Care Medicine*, 167(2), 211-277.
- Amir, R., Ben-Sira, D., & Sagiv, M. (2007). IGF-I and FGF-2 responses to wingate anaerobic test in older men. *Journal of Sports Science & Medicine*, 6(2), 227-232.
- Arnardóttir, R. H., Boman, G., Larsson, K., Hedenström, H., & Emtner, M. (2007). Interval training compared with continuous training in patients with COPD. *Respiratory Medicine*, 101(6), 1196-1204.
- Balady, G. J., Berra, K. A., Golding, L. A., Gordon, N. F., Mahler, D. A., Myers, J. N., et al. (2000). *ACSM's guidelines for exercise testing and prescription* (6th ed. ed.). Philadelphia, PA: Lippencott Williams & Wilkins.
- Bar-Or, O. (1987). The wingate anaerobic test. an update on methodology, reliability and validity. *Sports Medicine*, 4(6), 381-394.
- Bonnefoy, M., Kostka, T., Arsac, L. M., Berthouze, S. E., & Lacour, J. R. (1998). Peak anaerobic power in elderly men. *European Journal of Applied Physiology and Occupational Physiology*, 77(1-2), 182-188.

- Bourbeau, J., Nault, D., & Borycki, E. (2002). *Comprehensive management of chronic obstructive pulmonary disease*. Hamilton, ON: BC Decker Inc.
- Burdon, J. G., Juniper, E. F., Killian, K. J., Hargreave, F. E., & Campbell, E. J. (1982). The perception of breathlessness in asthma. *American Review of Respiratory Disease*, *126*(5), 825-828.
- Butcher, S. J. (2008). Modulation of ventilatory mechanics during exercise in ventilation-limited populations. *Applied Physiology, Nutrition & Metabolism*, *33*(3), 536-537.
- Butcher, S. J., & Jones, R. L. (2006). The impact of exercise training intensity on change in physiological function in patients with chronic obstructive pulmonary disease. *Sports Medicine*, *36*(4), 307-325.
- Canadian Thoracic Society. (2008). *Canadian thoracic society - guidelines & standards: COPD 2008 update slide kit*. Retrieved 2/17/2009, 2009, from [://www.lung.ca/cts-sct/guidelines-lignes_e.php](http://www.lung.ca/cts-sct/guidelines-lignes_e.php)
- Casaburi, R., Patessio, A., Ioli, F., Zanaboni, S., Donner, C. F., & Wasserman, K. (1991). Reductions in exercise lactic acidosis and ventilation as a result of exercise training in patients with obstructive lung disease. *The American Review of Respiratory Disease*, *143*(1), 9-18.
- Casaburi, R., Porszasz, J., Burns, M. R., Carithers, E. R., Chang, R. S., & Cooper, C. B. (1997). Physiologic benefits of exercise training in rehabilitation of patients with severe chronic obstructive pulmonary disease. *American Journal of Respiratory & Critical Care Medicine*, *155*(5), 1541-1551.
- Coppoolse, R., Schols, A. M., Baarends, E. M., Mostert, R., Akkermans, M. A., Janssen, P. P., et al. (1999). Interval versus continuous training in patients with severe COPD: A randomized clinical trial. *European Respiratory Journal*, *14*(2), 258-263.
- Celli BR, MacNee W. ATS/ERS Task Force. (2004). Standards for the diagnosis and treatment of patients with COPD: A summary of the ATS/ERS position paper. *European Respiratory Journal*, *23*(6), 932-946.
- Debigare, R., & Maltais, F. (2008). The major limitation to exercise performance in copd is lower limb muscle dysfunction. *Journal of Applied Physiology*, *105*(2), 751-752.
- Dekhuijzen, P. N., & Decramer, M. (1992). Steroid-induced myopathy and its significance to respiratory disease: A known disease rediscovered [Abstract]. *European Respiratory Journal*, *5*(8) 997-1003.
- Durstine, J. L., & Moore, G. E. (2003). *ACSM's exercise management for persons with chronic diseases and disabilities* (2nd ed. ed.). United States: American College of Sports Medicine.

- Gimenez, M., Servera, E., Vergara, P., Bach, J. R., & Polu, J. M. (2000). Endurance training in patients with chronic obstructive pulmonary disease: A comparison of high versus moderate intensity. *Archives of Physical Medicine and Rehabilitation*, 81(1), 102.
- Gosker, H. R., Hesselink, M. K. C., Duimel, H., Ward, K. A., & Schols, A M W J. (2007). Reduced mitochondrial density in the vastus lateralis muscle of patients with COPD. *The European Respiratory Journal: Official Journal of the European Society for Clinical Respiratory Physiology*, 30(1), 73-79.
- Harridge, S. D. R. (2007). Plasticity of human skeletal muscle: Gene expression to in vivo function. *Experimental Physiology*, 92(5), 783-797.
- Horowitz, M. B., Littenberg, B., & Mahler, D. A. (1996). Dyspnea ratings for prescribing exercise intensity in patients with COPD. *Chest*, 109(5), 1169-1175.
- Jagoe, R. T., & Engelen, M. P. (2003). Muscle wasting and changes in muscle protein metabolism in chronic obstructive pulmonary disease. *European Respiratory Journal - Supplement*, 46, 52s-63s.
- Kongsgaard, M., Backer, V., Jorgensen, K., Kjaer, M., & Beyer, N. (2004). Heavy resistance training increases muscle size, strength and physical function in elderly male COPD-patients--a pilot study. *Respiratory Medicine*, 98(10), 1000-1007.
- Kostka, T., Bonnefoy, M., Arsac, L. M., Berthouze, S. E., Belli, A., & Lacour, J. R. (1997). Habitual physical activity and peak anaerobic power in elderly women. *European Journal of Applied Physiology & Occupational Physiology*, 76(1), 81-87.
- Lacasse, Y., Brooks, D., & Goldstein, R. S. (1999). Trends in the epidemiology of COPD in Canada, 1980 to 1995. COPD and rehabilitation committee of the Canadian thoracic society. *Chest*, 116(2), 306-313.
- Maltais, F., LeBlanc, P., Jobin, J., Bérubé, C., Bruneau, J., Carrier, L. et al. (1997). Intensity of training and physiologic adaptation in patients with chronic obstructive pulmonary disease [Abstract]. *American Journal of Respiratory and Critical Care Medicine*, 155(2) 555-561.
- Meyer, K., Samek, L., Schwaibold, M., Westbrook, S., Hajric, R., Beneke, R., et al. (1997). Interval training in patients with severe chronic heart failure: Analysis and recommendations for exercise procedures. *Medicine & Science in Sports & Exercise*, 29(3), 306-312.
- Meyer, K., Samek, L., Schwaibold, M., Westbrook, S., Hajric, R., Lehmann, M., et al. (1996). Physical responses to different modes of interval exercise in patients with chronic heart failure--application to exercise training. *European Heart Journal*, 17(7), 1040-1047.

- Meyer, K., Schwaibold, M., Westbrook, S., Beneke, R., Hajric, R., Gornandt, L., et al. (1996). Effects of short-term exercise training and activity restriction on functional capacity in patients with severe chronic congestive heart failure. *American Journal of Cardiology*, 78(9), 1017-1022.
- Miller MR, Crapo R, Hankinson J, Brusasco V, Burgos F, Casaburi R, et al. (2005). General considerations for lung function testing. *The European Respiratory Journal: Official Journal of the European Society for Clinical Respiratory Physiology*, 26(1), 153-161.
- Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, et al. (2005). Standardisation of spirometry. *The European Respiratory Journal: Official Journal of the European Society for Clinical Respiratory Physiology*, 26(2), 319-338.
- Nici, L., Donner, C., Wouters, E., Zuwallack, R., Ambrosino, N., Bourbeau, J., et al. (2006). American thoracic Society/European respiratory society statement on pulmonary rehabilitation. *American Journal of Respiratory & Critical Care Medicine*, 173(12), 1390-1413.
- O'Donnell, D. E., Aaron, S., Bourbeau, J., Hernandez, P., Marciniuk, D., Balter, M., et al. (2007). Canadian thoracic society recommendations for management of chronic obstructive pulmonary disease--2007 update. *Canadian Respiratory Journal*, 14(Suppl B), 5B-32B.
- O'Donnell, D. E., Hernandez, P., Kaplan, A., Aaron, S., Bourbeau, J., Marciniuk, D., et al. (2008). Canadian thoracic society recommendations for management of chronic obstructive pulmonary disease - 2008 update - highlights for primary care. *Canadian Respiratory Journal*, 15(Suppl A), 1A-8A.
- O'Donnell, D. E., Lam, M., & Webb, K. A. (1998). Measurement of symptoms, lung hyperinflation, and endurance during exercise in chronic obstructive pulmonary disease. *American Journal of Respiratory & Critical Care Medicine*, 158(5 Pt 1), 1557-1565.
- O'Donnell, D. E., Revill, S. M., & Webb, K. A. (2001). Dynamic hyperinflation and exercise intolerance in chronic obstructive pulmonary disease. *American Journal of Respiratory & Critical Care Medicine*, 164(5), 770-777.
- O'Donnell, D. E., & Webb, K. A. (2008). The major limitation to exercise performance in copd is dynamic hyperinflation. *Journal of Applied Physiology*, 105(2), 753-755.
- Perrault, H. (2006). Efficiency of movement in health and chronic disease. *Clinical & Investigative Medicine*, 29(2), 117-121.
- Porszasz, J., Emtner, M., Goto, S., Somfay, A., Whipp, B. J., & Casaburi, R. (2005). Exercise training decreases ventilatory requirements and exercise-induced hyperinflation at submaximal intensities in patients with COPD. *Chest*, 128(4), 2025-2034.

- Puhan, M. A., Busching, G., Schunemann, H. J., VanOort, E., Zaugg, C., & Frey, M. (2006). Interval versus continuous high-intensity exercise in chronic obstructive pulmonary disease: A randomized trial. *Annals of Internal Medicine*, *145*(11), 816-825.
- Punzal, P. A., Ries, A. L., Kaplan, R. M., & Prewitt, L. M. (1991). Maximum intensity exercise training in patients with chronic obstructive pulmonary disease. *Chest*, *100*(3), 618-623.
- Rabe, K. F., Hurd, S., Anzueto, A., Barnes, P. J., Buist, S. A., Calverley, P., et al. (2007). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary.[see comment]. *American Journal of Respiratory & Critical Care Medicine*, *176*(6), 532-555.
- Ries, A. L., Bauldoff, G. S., Carlin, B. W., Casaburi, R., Emery, C. F., Mahler, D. A., et al. (2007). Pulmonary rehabilitation: Joint ACCP/AACVPR evidence-based clinical practice guidelines.[see comment]. *Chest*, *131*(5 Suppl), 4S-42S.
- Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52*, 591-611.
- Smodlaka, V. N., & Adamovich, D. R. (1974). Reconditioning of emphysema patients using interval training. *New York State Journal of Medicine*, *74*(6), 951-955.
- Swallow, E. B., Reyes, D., Hopkinson, N. S., Man, W. D., Porcher, R., Cetti, E. J., et al. (2007). Quadriceps strength predicts mortality in patients with moderate to severe chronic obstructive pulmonary disease. *Thorax*, *62*(2), 115-120.
- Troosters, T., Gosselink, R., & Decramer, M. (2004). Chronic obstructive pulmonary disease and chronic heart failure: Two muscle diseases? *Journal of Cardiopulmonary Rehabilitation*, *24*(3), 137-145.
- Vandewalle, H., Peres, G., & Monod, H. (1987). Standard anaerobic exercise tests. *Sports Medicine*, *4*(4), 268-289.
- Velloso, M., Stella, S. G., Cendon, S., Silva, A. C., & Jardim, J. R. (2003). Metabolic and ventilatory parameters of four activities of daily living accomplished with arms in COPD patients. *Chest*, *123*(4), 1047-1053.
- Vogiatzis, I., Georgiadou, O., Golemati, S., Aliverti, A., Kosmas, E., Kastanakis, E., et al. (2005). Patterns of dynamic hyperinflation during exercise and recovery in patients with severe chronic obstructive pulmonary disease. *Thorax*, *60*(9), 723-729.
- Vogiatzis, I., Nanas, S., Kastanakis, E., Georgiadou, O., Papazahou, O., & Roussos, C. (2004). Dynamic hyperinflation and tolerance to interval exercise in patients with advanced COPD. *European Respiratory Journal*, *24*(3), 385-390.

- Vogiatzis, I., Nanas, S., & Roussos, C. (2002). Interval training as an alternative modality to continuous exercise in patients with COPD. *European Respiratory Journal*, 20(1), 12-19.
- Vogiatzis, I., Terzis, G., Nanas, S., Stratakos, G., Simoes, D. C., Georgiadou, O., et al. (2005). Skeletal muscle adaptations to interval training in patients with advanced COPD. *Chest*, 128(6), 3838-3845.
- Wanger J, Clausen JL, Coates A, Pedersen OF, Brusasco V, Burgos F, et al. (2005). Standardisation of the measurement of lung volumes. *The European Respiratory Journal: Official Journal of the European Society for Clinical Respiratory Physiology*, 26(3), 511-522
- West, J. B. (2003). *Pulmonary pathophysiology the essentials* (6th ed. ed.). Philadelphia, PA: Lippencott Williams & Wilkins.
- Yan, S., Kaminski, D., & Sliwinski, P. (1997). Reliability of inspiratory capacity for estimating end-expiratory lung volume changes during exercise in patients with chronic obstructive pulmonary disease. *American Journal of Respiratory & Critical Care Medicine*, 156(1), 55-59.
- Yquel, R. J., Tessonneau, F., Poirier, M., Moinard, J., Pillet, O., & Manier, G. (2006). Peak anaerobic power in patients with COPD: Gender related differences. *European Journal of Applied Physiology*, 97(3), 307-315.

APPENDIX 1
CONSENT FORM

**Leg Muscle Power in Patients with COPD: An Examination of High Intensity
Exercise Testing Protocols**

CONSENT FORM

- I have read and I understand the information presented in this form.
- I have had the purpose, procedures and technical language of this study fully explained to me. I have been given ample time and opportunity to consider the above information, to inquire about details of the study and to decide whether or not to participate.
- Having read all pages of this information and consent form and understanding the requirements of the study, my signature below indicates that I voluntarily consent to participate in this study.
- I understand that I will receive a copy of this information and consent form.
- Please check the appropriate statement to indicate your decision:
_____ My family physician **can be** informed about my participation in this study, and, if required, consulted regarding my health and treatment.
or
_____ My family physician **cannot be** informed about my participation in this study, and, if required, consulted regarding my health and treatment.

Participant Name (print name)

Signature of Participant

Date

Signature of Witness

Date

I, or one of my colleagues, have carefully explained to the subject, the nature of the above research study. I certify that, to the best of my knowledge, the subject clearly understands the nature of the study and the demands, benefits and risks involved in participating in the study.

Investigator (or Designee) Name (please print)

Investigator (or Designee) Signature

Date

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