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Physiological and psychological responses to treadmill and cycle ergometer exercise testing in men and women with COPD

by

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Abstract

The purpose of this study was to examine the physiological and psychological responses to linear work rate treadmill and cycle ergometer exercise tests in men and women with chronic obstructive pulmonary disease (COPD). 12 men and 8 women with COPD completed one treadmill and one cycle cardiopulmonary exercise test (CPET) in randomized order. Before and after each CPET, the particpants completed measures of Self-Efficacy (SE), State-Anxiety, and Arousal. No significant differences were found between the physiological responses to cycle and treadmill CPET in either men or women. SE increased significantly as a result of the first test, regardless of exercise modality and sex. State anxiety was significantly reduced after the first test, whereas there was no significant change in arousal state. In conclusion there were no differences between the physiological and psychological responses to treadmill and cycle CPET in men and women with COPD.

TABLE OF CONTENTS

List of tables

List of Figures

List of abbreviations

AD ACL	Activation-Deactivation Adjective Check List
ADL	Activities of daily living
ANOVA	Analysis of variance
AT	Anaerobic threshold
BMI	Body mass index
Borg CRS	Borg category-ratio scale
BR	Breathing reserve
BP	Blood pressure
COPD	Chronic obstructive pulmonary disease
CFLH	Centre for Lung Health
CPET	Cardiopulmonary exercise test
CSA	Cross-sectional area
CSES	COPD self-efficacy scale
DH	Dynamic hyperinflation
DLco	Diffusion capacity
ECG	Electrocardiogram
EELV	End-expiratory lung volume
EFL	Expiratory flow limitation
EILV	End-inspiratory flow volume
ERV	Expiratory reserve volume
F	Female
FFM	Fat-free mass
FEV_1	Forced expiratory volume in 1 second
FRC	Functional residual capacity
FS	Feeling Scale
FVC	Forced vital capacity
Godin	Godin Leisure-time Exercise Questionnaire
HR	Heart rate
HR_{peak}	Peak heart rate
IC	Inspiratory capacity
LBM	Lean body mass
M	Male

M (SD)	Mean (standard deviation)
mph	miles per hours
MRC	Modified medical research counsile dyspnea scale
MSES	Multidimensional self-efficacy for exercise scale
MVC	Maximal ventilatory capacity
MVV	Maximal voluntary ventilation
ns	non significant
O_2	Oxygen
$P_{ET}co_2$	Partial pressure of end-tidal CO_2
$P_{ET}o_2$	Partial pressure of end-tidal O_2
PFT	Pulmonary function test
Po_2	Partial pressure of oxygen
Pco_2	Partial pressure of carbon dioxide
RER	Respiratory exchange ratio
PR	Pulmonary Rehabilitation
rpm	revolutions per minute
RR	Respiratory rate
RV	Residual volume
SE	Self-Efficacy
SpO_2	Oxygen saturation (by pulse oximetry)
STAI	State-trait anxiety inventory
VC	Vital capacity
TLC	Total lung capacity
Vco_2	Carbon dioxide output
V_E	Minute ventilation
V_{Epeak}	Peak exercise ventilation
V_E/Vo_2	Ventilatory equivalent for oxygen
V_E/Vco_2	Ventilatory equivalent for carbon dioxide $Vo_{2:}$ Oxygen uptake
Vo_{2max}	Maximal oxygen uptake, the highest attainable o_2-uptake for a given subject with a “Plateau” in O_2-uptake despite increasing work rate
Vo_{2peak}	Highest value of oxygen uptake actually attained (without Vo_2 plateau)
V_T	Tidal volume
WOB	Work of breathing

Chapter 1

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a serious public health problem and a major cause of chronic morbidity and mortality worldwide (Rabe, et al., 2007). COPD is a respiratory disorder predominantly caused by smoking (O'Donnell, et al., 2007; Lumb, 2000). COPD is characterized by progressive, partially reversible airflow obstruction, lung hyperinflation, frequent exacerbations, and systemic manifestations (O'Donnell, et al., 2007; Lumb, 2000). Most patients with COPD experience significant limitation in exercise capacity that affect daily living activities (Kaplan & Ries, 2005). Dyspnea, or shortness of breath, is one of the symptoms that impede most on COPD patients' daily life and health status (Nici, et al., 2006; Rabe, et al., 2007; Vogiatzis, Williamson, Miles, & Taylor, 1999; Wasserman, Hansen, Sue, Stringer, & Whipp, 2005). However, COPD is a very heterogeneous disease that affects people differently, and it may be beneficial to pay attention to differences between the COPD phenotypes emphysema and chronic bronchitis. The diagnosis of COPD and the quantification of respiratory impairment is easily made by resting spirometry: forced expiratory volume in one second (FEV_1) less than 70% of predicted in combination with the ratio of forced expiratory volume in one second to forced vital capacity (FEV_1/FVC) less than 0.7 is indicative of obstructive lung disease.

Historically, COPD has been seen as a disorder that effects males more frequently than females. Due to relatively recent changes in lifestyle behaviors of women (i.e., increased smoking rates), the number of females being diagnosed with COPD has now risen to equal or even exceed the number of men. The impact of COPD also appears to differ between sexes. A greater proportion of women tend to have chronic bronchitis, whereas the severity and prevalence of emphysema are greater in men (Becklake & Kauffmann, 1999; Han, et al., 2007).

According to 2005 estimates by the World Health Organization (WHO), 210 million people had COPD and three million people died of COPD (WHO, 2009). Around the same time, in Canada, COPD was the fourth leading cause of death in both men and women (Statistics Canada, 2009). This is seen despite the fact that mortality rate is difficult to determine in COPD, as COPD often is not coded as the primary cause of death (O'Donnell, et al., 2007). In general, COPD is a costly disease as the burden of the disease extends beyond the individual patient to the health care system and society as a whole (Mittmann, et al., 2008). As an example, in 2000 the direct costs of COPD in the USA were $18 billion, and an additional $14.1 billion were related to the indirect costs of the disease (Rabe, et al., 2007). The frequency and burden of COPD are likely to continue to grow in the years to come due to the expected shift in the average age of the population, where a greater proportion of the population will be older than 65 years old, particularly women, who have a greater life expectancy than men (O'Donnell, et al., 2007; Rabe, et al., 2007).

There is no cure for COPD. Self-management programs have shown to produce beneficial health outcomes for people suffering from a variety of chronic diseases including COPD (Bourbeau, et al., 2006; Bourbeau, Nault, & Dang-Tan, 2004). Pulmonary Rehabilitation (PR) in particular has been successful in improving symptoms, patient functioning, exercise capacity, and quality of life (QOL) (Celli, et al., 2004; Kaplan & Ries, 2005; Ries, Kaplan, Limberg, & Prewitt, 1995), as well as reducing hospitalizations and physician visits (Goldstein, 2003). PR programs often involve patient assessment, education, physical and respiratory care, exercise training, nutritional intervention, and psychosocial support (Eakin, Sassi-Dambron, Kaplan, & Ries, 1992; Nici, et al., 2006). Exercise is a major component of any PR program and has many beneficial effects: improved cardiovascular endurance, improved muscular strength and endurance, improved blood pressure, heart rate, lipid control, and blood sugar control, stronger immune system, decreased rate of depression and anxiety, and reduced risk of osteoporosis, cancer and cardiovascular disease (Whaley, Brubaker, Otto, & Armstrong, 2006). Perhaps most importantly, exercise is seen to break the vicious cycle of dyspnea (O'Donnell, et al., 2007; Whaley, et al., 2006). Despite all the beneficial effects of exercise and PR, adherence to exercise programs following PR is still low. Therefore, it is important to emphasize behavioral interventions and develop strategies to maximize health benefits, post rehabilitation adherence, and health gain maintenance (Ries, et al., 1995). Additionally, it is important to examine motivation to engage in the PR behaviors, including such variables as personal self-efficacy for exercise and breathing management.

Cardiopulmonary Exercise Test

Although FEV_1 is a good indicator of disease progression and mortality, resting physiological values cannot adequately predict exercise intolerance (Celli, et al., 2004). A cardiopulmonary exercise test (CPET) is an excellent objective measure of exercise capacity and limitations to exercise, and is based on the principle that system failure typically occurs while the system is under stress (Whaley, et al., 2006). CPET is a common and appropriate part of preventive and rehabilitative exercise programs (Nici, et al., 2006; Palange, et al., 2000), and is often the first thing the patient encounters in PR programs.

The exercise mode used for CPET testing has been a topic of debate. The selection of an appropriate CPET modality should be based on the purpose of the test and the health and fitness status of the client. Too often though, the choice of test is based on the availability of equipment, habits of the testers, preference of physicians, or lack of knowledge (Stringer & Wasserman, 2005; Whaley, et al., 2006). Importantly, the exercise mode can influence the patient’s perception and therefore confidence for exercise, the cardiorespiratory data obtained from the tests, and correspondingly the interpretation of the results.

Recent research has examined the use of treadmill versus a cycle ergometer on cardiopulmonary exercise testing in individuals with COPD. Researchers have found the treadmill protocol to be advantageous in evaluation of COPD patients (Hsia, Casaburi, Pradhan, Torres, & Porszasz, 2009); however, more research is needed to confirm these results. Further, inherent differences between male and female COPD patients with respect to the underlying disease pathophysiology and psychology may influence responses to cycle or treadmill exercise.

In response to the need for further research in this area, the aim of the present study is to compare an incremental treadmill protocol to a traditional linear incremental cycle ergometer protocol. Both physiological and psychological responses to the two tests will be examined, with specific attention to differences between men and women. The primary research question is: Are the physiological and psychological responses to linear work rate treadmill and cycle ergometer exercise different in men and women with COPD?

LITERATURE REVIEW

Exercise capacity is determined by a number of factors such as ventilatory limitation, gas exchange, muscular function, and cardiovascular limitations (Oga, et al., 2005), and the measurement of oxygen uptake (VO_2) and carbon dioxide output (VCO_2) is a good indicator of how well the cardiovascular and pulmonary systems work to maintain their primary function of supporting adequate cellular respiration (Wasserman, et al., 2005). Measureable and progressive deterioration of exercise capacity has been observed in COPD patients over time, with a more rapid decline in VO_2 values compared to FEV_1 values (Oga, et al., 2005).

Pulmonary system and exercise in health

As metabolic rate increases with exercise, there is an increased demand on the pulmonary system to maintain gas exchange. The pulmonary system in young and healthy adults has a great reserve to increase ventilation, and thus, the pulmonary system is seldom a limiting factor even at maximal exercise. Dynamic exercise causes an in increase metabolic demand that requires greater minute ventilation (V_E) to maintain arterial partial pressure of oxygen (PO_2) and partial pressure of carbon dioxide (PCO_2). The increase in V_E results from increases in both tidal volume (V_T) and breathing frequency. With progressive exercise, the operating lung volumes and the inspiratory capacity (IC) normally change in order to increase $V_{T.}$ This typically occurs through a combination of decreased end-expiratory lung volume (EELV) and increased end-inspiratory lung volume

(EILV). The reduction in EELV places the diaphragm at a more advantageous mechanical position, and thereby decreases the inspiratory work of breathing (WOB) (Lumb, 2000; O'Kroy, Lawler, Stone, & Babb, 2000). However, exercise still increases the total WOB. Whereas the elastic WOB increase in order to increase V_T, the resistive WOB is increased as a result of increased airflow.

Ventilatory limitations to exercise and expiratory flow limitation (EFL) in COPD

The lungs may become a limiting factor during exercise in healthy elderly populations because of a reduction in elastic recoil, changes in surface area for gas exchange, and diffusion capacity which naturally occur with aging (Haverkamp, Dempsey, Miller, Romer, & Elderige, 2005). However, these changes are much more prominent in patients with COPD, and as a result of narrowing of the airways and loss of elastic recoil of the lung parenchyma, airway obstruction occurs. This leads to a reduction in expiratory flow rate, and thus, the expiratory flow volume curve measured by Spirometry, typically has a scooped appearance with an initial peak of moderately high flow followed by a rapid reduction in flow because of airway collapse. As the patient's ability to expel air is reduced, the expiratory time increases and the subject may not be able to finish breathing out before they need to take a new breath in. This may cause an increase in the volume of trapped air in the lungs at the end of expiration and this shift in operating lung volumes is recognized as dynamic hyperinflation (DH)(O'Donnell, et al., 2007).

Breathing at higher lung volumes is initially beneficial because it improves the generation of expiratory flow. However, as EELV approaches total lung capacity (TLC), DH occurs in combination with decreased lung compliance and increased mechanical WOB. As a result of this, the patient may experience greater levels of dyspnea (Lumb, 2000). When the expiratory flow rate during normal tidal breathing is similar to the subject's maximal expiratory flow, further increase in flow is impossible, and expiratory flow limitation (EFL) often occurs in patients with COPD. As the ventilatory demands increase in patients with EFL, a progressive reduction in IC and elevation of EELV may further increase DH. Progressive DH constrains the increase in V_T, and a further increase in ventilation can therefore only occur through an increase in breathing frequency. However, increasing breathing frequency may further exacerbate DH and lead to increased shortness of breath and compromise exercise tolerance. Several authors, (Harms & Rosenkranz, 2008; McClaran, Wetter, Pegelow, & Dempsey, 1999; Sheel & Guenette, 2008) found EFL to be more common in athletic young women compared to age matched men, and they believe the anatomically smaller lungs and airways in women can explain their reduction in expiratory flow and vital capacity.

Cardiopulmonary Exercise Test

The CPET is a useful tool to evaluate the effectiveness of the cardiovascular and respiratory systems under stress. In addition to the evaluation of individuals' exercise capacity and limitations to exercise, the test can be used for pre-operational risk assessment, differential diagnosis determination, and treatment (PR and medical regimen) prescription and evaluation (Wasserman et al., 2005). As several diseases can reduce the ability for oxygen uptake (VO_2), the use of a CPET to determine VO_2 at which exercise limitation occurs can be a valuable part of the patient assessment (Wasserman et al., 2005).

Maximal aerobic power, or maximal oxygen uptake (VO_{2max}), is probably the best and most reproducible index of cardiopulmonary fitness and disability (Wasserman et al., 2005). It is a strong independent risk factor for all-cause and cardiovascular mortality (Ashley, Myers, & Froelicher, 2000; Nici, et al., 2006). Maximal cardiac output, arterial O_2 content, the distribution of cardiac output to the working muscles, and the muscles ability to extract O_2 are all determinants of VO_{2max}. VO_{2max} decreases with age, but at any age women have 10-20% lower VO_{2max} then men (Milani, Lavie, Mehra, & Ventura, 2006). Patients may not reach their true VO_{2max} and clinically we therefore use the term VO_{2peak} to describe the highest oxygen uptake achieved during an exercise test. COPD patients may not reach their true VO_{2max} during exercise because of ventilatory limitation (Christensen, Ryg, Edvardsen, & Skjønsberg, 2004; Johnson, Beck, Zeballos, & Weisman, 1999; Mathur, Revill, Vara, Walton, & Morgan, 1995). However, VO_{2peak} has been found to be an important predictor of survival in COPD patients (Oga, et al., 2005)**.** Also, the increase in VO_2 relative to the increase in work rate during progressive exercise in COPD may be similar to healthy subjects, because COPD patients are more limited in their capability to eliminate CO_2 rather than transporting O_2 to the mitochondria (Wasserman et al., 2005).

The major link between the circulatory and ventilatory responses to exercise is carbon dioxide production (VCO_2), as it serves as a respiratory control function (Milani, et al., 2006). At the onset of exercise, increased matching of ventilation and perfusion will result in an initial decrease in the ventilatory slope (V_E/VCO_2). As exercise progresses, the V_E/VCO_2 remains relatively constant because V_E follow VCO_2 linearly. As the metabolic demands of exercise increase further, glycolysis is accelerated and an increase in lactate production and accumulation occurs. Excess non-metabolic carbon dioxide is produced as the lactic acid is buffered by bicarbonate (Milani, et al., 2006). Chemoreceptors in the carotid bodies detect the increase in VCO_2 and trigger an increase in V_E. As a result of the additional ventilatory stimulus following the respiratory acidosis, an increase in V_E/ VCO_2 is seen at peak exercise (Milani, et al., 2006). Patients with pulmonary disease often have greater ventilatory slopes (V_E/VCO_2) than normal healthy subjects (Milani, et al., 2006; O'Donnell, 1994) because of greater ventilatory drive and/or because of increased dead space ventilation (Milani, et al., 2006).

An individual's ventilatory capacity is often determined by comparing the patient's maximal voluntary capacity (MVV), measured at rest or predicted from FEV_1 x 35, to maximal minute ventilation (V_{Emax}) during exercise. Work rates that require ventilation greater than MVV cannot be sustained, and the difference between MVV and V_{Emax} is defined as the patient's breathing reserve (BR). Healthy adults have a substantial BR, but the value is often close to zero in COPD patients (Wasserman, et al., 2005). A better method to estimate ventilatory limitation during exercise is by analyzing tidal volumes, operating lung volumes, and flow rates by plotting the tidal exercise flow-volume loop within the maximal flow-volume envelope. Pre-exercise maximal expiratory and inspiratory maneuvers determine the maximal flow-volume envelope, and normal tidal breathing during exercise determines the tidal flow-volume loops (Johnson, et al., 1999). To plot the two curves correctly together and to determine EELV inspiratory capacity (IC) is measured at rest and during exercise (Johnson, et al., 1999). The maximal flow rates at any given lung volume is normally greater than the flow rates reached during exercise, but if the tidal exercise flow-volume loop intersects the boundary of the expiratory portion of the maximal flow-volume loop, it is a good indication of expiratory flow limitation (EFL) and increased WOB with exercise (Sheel & Guenette, 2008). COPD patients, and perhaps especially women, have smaller expiratory flow volume loops, and this reflects their reduced ability to increase ventilation with progressive exercise without experiencing EFL. Progressive decrease in IC with exercise is a good indicator of DH, decreased exercise capacity, and exertional dyspnea (Sheel & Guenette, 2008).

Numerous protocols, exercise devices and measuring systems are available for CPET. The two most common modes of exercise are the bicycle ergometer and the treadmill, and a wide variety of test protocols such as progressive incremental exercise protocols, continuous ramp protocols, multistage exercise protocols, and constant work rate protocols are available for each of the exercise modes. However, there is currently no consensus which exercise mode or protocol is preferable (Whaley, et al., 2006).

Treadmill versus Cycle ergometer

Activation of large muscle groups is necessary for internal respiration to be stimulated adequately to stress the cardiovascular and pulmonary systems during CPET (Wasserman et al., 2005). Exercise on both treadmill and cycle ergometer activates large muscle groups, but the physiological and the psychological responses are likely to differ between the two test modalities. The main advantage of the cycle ergometer is the precise quantification of external work performed by the patient (Wasserman et al., 2005; Whaley, et al., 2006), as well as a more regular increase in VO_2 because of a more constant increase in work rate (Wasserman et al., 2005). On the contrary, the activity of walking is more familiar for most people. This in combination with activation of greater muscle mass while walking may result in higher VO_{2peak} and anaerobic threshold (AT) values, despite similar increases in maximal heart rate (HR), V_E, and blood lactate levels (Wasserman et al., 2005). There are, however, practical advantages of the cycle ergometer such as cost, space, and noise. Also, with the reduction of upper body movements on the cycle, the occurrence of electrocardiogram (ECG) artifacts are diminished and the measurement of blood pressure (BP) and blood samples are easier (Wasserman, et al., 2005; Whaley, et al., 2006). Elderly, uncoordinated, and disabled patients may perceive the cycle ergometer as being safer with a lower risk of falling. Due to the fear of falling off the treadmill, individuals may hold on to the handrails on the treadmill for support. This may decrease the metabolic demand of the exercise and thereby alter the accuracy of the test (Wasserman, et al., 2005). Change in respiratory muscle recruitment and breathing pattern may also occur if the subject holds on to the handrails, but a similar change may result from holding onto the cycle handlebars (Marin, et al., 2001).

Several researchers have compared walking and cycling in COPD patients (Christensen, et al., 2004; Hsia, et al., 2009; Mathur, et al., 1995; Murray, Waterman, Ward, Baird, & Mahler, 2009; Palange, et al., 2000). Most researchers have found COPD patients to perceive greater breathlessness with walking and greater leg discomfort with cycling (Man, et al., 2003; Murray, et al., 2009; Palange, et al., 2000; Pepin, Saey, Whittom, LeBlanc, & Maltais, 2005). However, O'Donnell et al, 1994 found 80% of COPD patients to terminate cycle exercise because of breathlessness alone or in combination with leg fatigue. In contrast, 76% of healthy controls terminated cycling because of leg fatigue. Typically, those COPD patient’s who terminated exercise because of breathing discomfort had greater airflow limitation and impairment in dynamic mechanisms during exercise than healthy participants (O'Donnell, 1994).

Palange, et al., 2000 found the metabolic and ventilatory responses to be different between the two exercise modes where the ventilatory slopes (ΔV_E /ΔVCO_2) and $\Delta HR/\Delta VCO_2$ were greater with incremental shuttle walking compared to cycling, despite similar values for VO_{2peak}, V_E, and HR, and lower peak blood lactate and VCO_2 values. They attribute the increased ventilatory demand with walking to a reduction in pulmonary gas exchange efficiency (greater dead-space ventilation), increased arterial hypoxemia, and differences in muscle recruitment. Their belief was that different types of muscle fibers and muscle groups recruitment (i.e arm and trunk muscles), can potentially increase afferent inputs that increase ventilation (Palange, et al., 2000). Afferent input from arm/trunk is less likely with cycling because of the fixed position of the arms on the handlebars (Palange, et al., 2000). However, the participants in Palange and colleagues study (2000) performed the incremental shuttle walk test and the physiological effort of walking on flat surface are likely different from walking on a treadmill. Thus, comparing these results to those obtained during a treadmill test may be challenging.

Although some researchers found VO_{2peak} to be similar for walking and cycling (Mathur, et al., 1995; Palange, et al., 2000), more recent research has reported VO_{2peak} to be higher on the treadmill compared to the cycle ergometer (Christensen, et al., 2004; Hsia, et al., 2009; Murray, et al., 2009). The overwhelming demand placed on the smaller muscle mass (i.e., quadriceps) during cycling leads to greater lactate production (Christensen, et al., 2004; Mathur, et al., 1995; Palange, et al., 2000). This results in higher VCO_2 levels, which may trigger increased ventilation. Increased lactate levels during cycling may therefore also be associated with earlier onset of breathlessness (Murray, et al., 2009) and leg discomfort in comparison to walking (Mathur, et al., 1995; Palange, et al., 2000). Walking may also better simulate the physiologic and metabolic stresses experienced during activities of daily living (ADL), and provide a better picture of the patient’s functional capacity during ADL. Walking compared to cycling has been shown to result in greater oxygen desaturation (Christensen, et al., 2004; Hsia, et al., 2009; Man, et al., 2003; Murray, et al., 2009), and the underestimation of oxygen desaturation during cycling could cover up the need for additional oxygen with exercise.

Protocols

One of the most commonly utilized protocols among clinical practice is the Bruce treadmill protocol. The Bruce protocol is a multistage exercise protocol with an increase in work rate every 3 minutes. High initial work rate combined with the large and uneven increments during the test often result in rapid fatigue and inaccurate estimation of exercise capacity (Buchfuhrer, et al., 1983; Hsia, et al., 2009; Ingle, 2007; Myers, et al., 1991; Porszasz, Casaburi, Somfay, Woodhouse, & Whipp, 2003). Therefore this protocol may not be ideal for individuals with compromised exercise capacity. A ramped Bruce protocol may be more appropriate because of a smoother and continuous increase in speed and grade (Myers, et al., 1991), but the initial work rate remains high and may even approach maximal exercise capacity in severely impaired patients.

The use of constant work rate protocols on the treadmill or the cycle is gaining clinical popularity. These protocols can be particularly useful for evaluating the response to therapeutic interventions such as medications and PR. However in order to apply a constant work rate that is appropriate performance of a maximal incremental exercise test must precede the constant work rate test. Therefore, an appropriate maximal incremental exercise test must serve as base measurement.

Several maximal incremental treadmill exercise protocols exist, but in contrast to the cycle ergometer, a linear increase in work rate on the treadmill has been somewhat difficult to accomplish. The advantage of linear increase in work rate is a steady rise in physiological responses that permits a more accurate estimation of VO_2 (Buchfuhrer, et al., 1983; Myers, et al., 1991; Whaley, et al., 2006) and a more precise evaluation of exercise intolerance (Wasserman, et al., 2005). The linear relationship of VO_2 and power output is especially beneficial for determining anaerobic threshold (AT) at submaximal exercise, and as AT sets the limit for sustainable exercise it is very useful for exercise prescription (Wasserman, et al., 2005).

Attempts have been made to approximate linear work rate on the treadmill by either maintaining a constant inclination while increasing the speed linearly or maintaining a constant speed while increasing the angle of inclination linearly. For example, the Balke and modified Balke treadmill protocols increase work rate through a combination of constant speed and an increase in inclination every minute or two. However, these tests often take an extended period of time to complete, resulting in other reasons for test termination than appropriate stress of the cardiopulmonary system. A further limitation of these protocols is that they do not take into consideration the effect of the individual's body weight on the work done against gravity while walking up an incline (Porszasz, et al., 2003).

Porszasz and coworkers (2003) included weight in the following algorithm when estimating work rate on the treadmill: $WR(t) = m*g*v(t)*\sin(\alpha)$, where WR(t) is the time course of work rate in watts, m is the body mass in kilograms, g is the gravitational acceleration (9.81m*s-2), v(t) is the time course of velocity in meters per second, and α is the angle of inclination. This protocol is thought to be valuable in subjects with severely limited exercise tolerance (i.e. lung patients), by bringing subjects to symptom limited exercise in 10 minutes through a combination of low initial metabolic demand and a constant rate of change in work rate. However, not until recently did the same research group compare this linear incremental CPET to the Bruce protocol and a traditional cycle ergometer test in 16 COPD patients (FEV_1<60%) (Hsia, et al., 2009). The initial metabolic demand was much greater with the Bruce protocol resulting in early test termination (5.1±1.8 minutes) and sparse data around AT. On the contrary, the linear treadmill test lasted near the target duration of 10 minutes and produced a similar response course as the cycle ergometer, but with important physiological differences. V_{Epeak} was similar for all three tests, but in agreement with previous research, VO_{2peak}, peak VCO_2, and oxygen desaturation were significantly greater with both walking tests. In contrast to Palange et al., (2000) V_E/VCO_2 was significantly greater on the cycle ergometer (Hsia, et al., 2009). However, at iso-VO_2 there was no difference in V_E /VCO_2. Also, there was no iso-VO_2 difference in DH between cycle and treadmill tests. Peak Borg leg discomfort was similar for all three tests, whereas peak Borg breathlessness was greater with both walking tests.

Duration

Several authors seem to agree that the most informative test, resulting in highest VO_{2peak} values, lasts between 8 and 12 minutes (Ashley, et al., 2000; Buchfuhrer, et al., 1983; Myers, et al., 1991; Ross, et al., 2003; Wasserman, et al., 2005; Whaley, et al., 2006; Will & Walter, 1999). Shorter test durations, with rapid increases in work rate and high initial metabolic demand, may result in insufficient data acquisition for proper analysis (Wasserman, et al., 2005) and a nonlinear relationship between VO_2 and power output (Milani, et al., 2006). On the other hand, long test durations may result in too small of an increase in work rate and the test may be terminated because of boredom, discomfort (Wasserman, et al., 2005), fatigue or orthopedic factors (Milani, et al., 2006). Therefore, lower VO_{2peak} and V_{Emax} values may result from tests that are too long and too short in duration (Buchfuhrer, et al., 1983; Will & Walter, 1999). However, little research has been done on the most appropriate test duration with CPET in COPD patients though. Benzo, Paramesh, Patel, Slivka, & Sciurba (2007) compared four incremental cycle tests with different increase in work rate, and concluded that test durations between 5 and 9 are most beneficial for patients with COPD.

CPET in COPD

The debate regarding the optimal exercise mode for conducting the CPET among COPD patients persists. Most studies have been conducted using small sample sizes with predominately male samples and little investigation of the effects of gender. Varying methodology as well as high response variability also makes the result of different studies difficult to interpret and compare. Several relevant variables including sex, body composition, muscle strength, muscle fatigue, COPD phenotype, disease severity, and psychological factors (i.e., personal self-efficacy for exercise and breathing management) may play an important role when determining whether the treadmill or the cycle ergometer should be the recommended mode of testing.

Dyspnea and perceived breathlessness

The measurement of dyspnea by the modified MRC scale in COPD patients has been seen to be a good predictor of walking distance (Marin, et al., 2001) and a better predictor of five years survival than airway obstruction (Oga, et al., 2005). During exercise, an increased sensation of dyspnea is related to the increase in WOB as a consequence of changes in operational lung volumes, DH, V_T, and IC (Emtner, Porszasz, Burns, Somfay, & Casaburi, 2003), and patients with similar degrees of airflow limitation may have very different perceptions of breathlessness (Marin, et al., 2001).

The prevalence of activity related breathlessness is seen to increase with age (Ofir, Laveneziana, Webb, Lam, & O'Donnell, 2008). Despite similar effects of aging on the function of the normal healthy respiratory system in men and women (i.e., progressive muscle weakness, decreased compliance of respiratory system, and change in V/Q relationship), women report exertional breathlessness more frequently and with greater intensity than their age matched male counterparts (Camp, O'Donnell, & Postma, 2009; Ofir, et al., 2008). The smaller ventilatory capacity in women (Ofir, et al., 2008) is possibly related to the natural anatomic differences in size of lungs, airways, and respiratory muscles between the sexes (Camp, et al., 2009). For a standardized physical activity task, women must therefore engage a greater fraction of their maximal V_E and muscle effort (Camp, et al., 2009).

The differences in respiratory sensation described in health, seem to persist and become amplified with COPD as the pathophysiological effects further reduce the ventilatory reserve in women (de Torres, et al., 2005). Women with COPD therefore tend to be more symptomatic than their male counterparts, even when matched for airway obstruction (Camp, et al., 2009; Di Marco, et al., 2006; Ofir, et al., 2008). However, the physiological reasons for the differences seen in symptom perception during physical activity between men and women remain poorly understood (Camp, et al., 2009). As the sensation of dyspnea appears to be enhanced in women, they will most likely report greater levels of breathlessness during CPET compared to men of the same age and disease severity.

Body Composition and Fatigue

Increased muscle strength is associated with decreased effort and dyspnea during exercise (Stendardi, Grazzini, Gigliotti, Lotti, & Scano, 2005). However, weight loss and associated muscle wasting is frequently reported in patients with COPD. O'Donnell et al. (2007) estimate that muscle wasting could affect up to 30% of this patient population, and especially those with greater disease severity. Low Body Mass Index (BMI) relates to poor prognosis (Landbo, Prescott, Lange, Vestbo, & Almdal, 1999) and increased mortality in COPD (O'Donnell, et al., 2007; Landbo, et al., 1999; Schols, Slangen, Volovics, & Wouters, 1998). However, the relationship between disease severity and significance of BMI is somewhat unclear. Schols et al. (1998) found the significance of BMI to be independent of degree of airflow obstruction. Conversely, Landbo et al. (1999) found BMI to be a stronger predictor of airflow obstruction among patients with severe COPD. There is also dispute regarding the threshold values related to BMI and mortality risk among individuals with COPD, where Schols et al. (1998) noted a BMI threshold of < 25 (kg/m^2), which is the upper-normal level of BMI, and Celli, et al. (2004) noted a BMI threshold of < 21 (kg/m^2). Weight loss in COPD may be associated with increased metabolic rate and energy expenditure without an adequate increase in energy intake (Schols et al., 1998), and tissue depletion could also be related to systemic inflammation (Schols et al., 1998), immobility, and hypoxia (O'Donnell, et al., 2007). When matched for the same airway obstruction (FEV$_1$), de Torres et al. (2005) found women to present with lower BMI and decreased nutritional status compared to men.

COPD patients often show structural as well as functional changes in peripheral muscles, especially the quadriceps muscle, and characteristic features include decreased oxidative capacity, atrophy and loss of type I fiber, and weakness (Bernard, et al., 1998; Mador, Bozkanat, & Kufel, 2003; Man, et al., 2003; Palange, et al., 2000; Saey, et al., 2003). In general, the wasting of fat free mass (FFM) (Engelen, Schols, Does, & Wouters, 2000; Gosker, et al., 2003), especially the extremity FFM, seems to be independent of COPD phenotype and airflow obstruction (Engelen, et al., 2000).

Measurement of lean body mass (LBM) or fat free mass (FFM) may be a better predictor of mortality and functional capacity in COPD than BMI because FFM is an indirect measure of muscle mass, which is a strong predictor of muscle strength in COPD (Gosker, et al., 2003). When comparing strength to muscle cross-sectional area (CSA) in COPD patients and healthy controls, Bernard, et al. (1998) found the ratio (strength/muscle CSA) to be similar for the two groups. They concluded that the loss of muscle mass in proportion to the decrease in strength suggests that the contractile apparatus of the muscles are intact, and that muscle deconditioning and disuse atrophy possibly explain the peripheral muscle dysfunction seen in COPD patients (Bernard, et al., 1998). However, Gosker, et al. (2003) found a weaker relationship between FFM and exercise capacity in COPD patients compared to healthy controls.

The peripheral muscle alterations seen in patients with COPD may increase the susceptibility to contractile fatigue at peak exercise (Stendardi, et al., 2005). Muscle fatigue with walking exercise is rather uncommon as exercise termination is more likely a result of ventilatory limitation, before the onset of quadriceps/peripheral muscle fatigue (Man, et al., 2003; Stendardi, et al., 2005). However, contractile fatigue of the quadriceps muscle is very common with cycle exercise because smaller muscle mass must perform the same workload as on the treadmill (Man, et al., 2003; Saey, et al., 2003). COPD patients experience much greater quadriceps fatigue during cycle exercise than age-matched healthy controls (Mador, et al., 2003). Other patients may become ventilatory limited even before they reach either circulatory- or muscle system limitation (Mador, et al., 2003; Man, et al., 2003; Saey, et al., 2003). Factors such as age, BMI, resting lung function, physical activity, muscle mass, test duration, perceived symptoms at peak exercise or reason for termination may not predict who will fatigue more quickly with exercise, as differences in intrinsic muscle differences seem to play an important role (Saey, et al., 2003).

With progressive exercise, increased WOB and DH, the respiratory muscles may fatigue because the increased muscular force required to ventilate the lungs during heavy exercise is closer to maximal force of the respiratory muscles (Sheel & Guenette, 2008). Redistribution of blood flow from the lower limbs to the respiratory muscles may therefore contribute to additional peripheral muscle fatigue (Mador, et al., 2003; Saey, et al., 2003; Stendardi, et al., 2005).

Female COPD patients have lower BMI and smaller muscle mass compared to men, and may therefore experience greater muscle fatigue and decreased exercise capacity on the cycle ergometer compared to men.

COPD phenotypes and COPD in women

Even though pathophysiological changes in emphysema and chronic bronchitis are distinct and the patients may experience different symptoms of the disease, a clear differentiation is often difficult to make because of overlap, and hence, the global diagnosis of COPD. Emphysema is characterized by increased airspaces and destruction of alveolar walls and capillary beds, and the loss of elastic tissue and reduction in elastic recoil may cause premature airway closure on expiration, and thus EFL and reduced ventilatory capacity. Chronic bronchitis is characterized by airway narrowing because of inflammation, thickening of airway walls, and excessive mucous production. A productive cough is a typical symptom of chronic bronchitis, and the increased airway resistance decreases ventilatory capacity. Increased airway resistance can occur with emphysema as well, as the loss of elastic tissue may reduce the radial traction of the airways.

The relation between sex and phenotypes remains a topic of research interest, but as both airway behavior and clinical presentation of airway disease differ between men and women throughout life, biological as well as sociocultural factors may play a part (Becklake & Kauffmann, 1999). Martinez, et al. (2007) used data from the National Emphysema Treatment Trial and found more airway disease in women and more emphysema in men. Women seem to be more susceptible to the detrimental effects of smoking (Becklake & Kauffmann, 1999; Han, et al., 2007; Leynaert, Bousquet, Henry, Liard, & Neukirch, 1997; Lindberg, et al., 2005; Sin, Cohen, Day, Coxson, & Pare, 2007). Gold and coworkers (1996) confirmed this when they studied almost 10 000 adolescents aged 10 to 18 over a period of 15 years and found girls to be more vulnerable to the effects of smoking on development of lung function than boys. Several researchers have found women, after matching for lung function, to be younger, have shorter smoking history, and report greater dyspnea compared to their male counterparts (de Torres, et al., 2005; Han, et al., 2007; Martinez, et al., 2007; Ofir, et al., 2008; Watson, et al., 2006)**.** Female smokers are also seen to have a greater yearly decline in FEV_1 % predicted compared to male smokers (Camp, et al., 2009).

Why smoking affects the airways and lung parenchyma of men and women differently remains unclear, but the thicker airway walls and smaller lumens in women may play a part (Becklake & Kauffmann, 1999; Martinez, et al., 2007). Several other factors may also influence this difference: sex hormones (Becklake & Kauffmann, 1999; Camp, et al., 2009; Han, et al., 2007; Sin, et al., 2007), immunological differences (Becklake & Kauffmann, 1999; Han, et al., 2007), differences in particle deposition (Sin, et al., 2007) and site of particle deposition (Camp, et al., 2009), underreported tobacco use in women, “dose-dependent effect” in which smaller airways in potentially have a proportionately greater exposure for each cigarette, influence of secondhand smoking, cigarette brand (Camp, et al., 2009; Han, et al., 2007), inhalation/manner of smoking (Camp, et al., 2009; Sin, et al., 2007), and ability to stop smoking (Xu, Li, & Wang, 1994). Considering the fact that women live longer than men, they are likely to live longer with COPD and early detection of airway disease to stop deterioration is of major importance. It is therefore alarming that the likelihood of being diagnosed with COPD is smaller in woman than men, and only 22% of physicians are likely to recommend spirometry testing in women who present with shortness of breath (Chapman, Tashkin, & Pye, 2001).

Exercise modality and gender differences

Women are at greater risk of developing COPD than age-matched men (de Torres, et al., 2005; Han, et al., 2007; Martinez, et al., 2007; Ofir, et al., 2008; Watson, et al., 2006)**.** Little research has been undertaken to investigate gender difference in performance on the CPET using either the treadmill or the cycle ergometer. Due to anatomical differences women have more EFL, increased DH and decreased ventilatory capacity (Harms & Rosenkranz, 2008; McClaran, et al., 1999; Sheel & Guenette, 2008). As a result, they are less capable of increasing V_T, and increases in V_E must occur along with an increase in breathing frequency. These changes may further increase DH and thus the sensation of dyspnea (O'Donnell, et al., 2007). Since females have less muscle mass than men, they may experience greater muscle fatigue with cycling compared to walking, which may increase their ventilation with cycling. Therefore, there is increased probability that women will experience greater EFL, DH and dyspnea with the cycle ergometer compared to men of the same age and functional impairment.

Self-Efficacy

Health habits exert a major impact on the quality of peoples' physical and psychological well-being, and the accumulation of unhealthy behaviors and harmful environments may lead to chronic health problems (Bandura, 1997). A robust association has been found between self-efficacy (SE) and performance of health behavior, exercise behavior and exercise adherence in a variety of populations (Bandura, 1997; Maddux, 1995; McAuley, 1993; McAuley, Jerome, Elavsky, Marquez, & Ramsey, 2003; Rodgers, Wilson, Hall, Fraser, & Murray, 2008; Rodgers, Hall, Blanchard, McAuley, & Munroe, 2002). Interventions to increase SE have been successful and are associated with improved functional status and health related outcomes such as physical fitness (Bandura, 1997; Maddux, 1995; McAuley, 2003).

SE is defined as an individual's confidence for organizing and performing a specific behavior or set of behaviors that is required to produce a desired outcome (Bandura, 1977, 1997)**.** Therefore, SE is not about skills per se, but rather about what a person can do with whatever skills they possess in challenging situations (Bandura, 1997). According to Bandura (1997), behavior change and maintenance are functions of 1) outcome expectations – expectations and beliefs about whether a given behavior will lead to certain outcomes; and 2) efficacy expectations – expectations and beliefs about one's ability to engage in or execute the behavior that will lead to given outcomes. Efficacy and outcome expectations need to be differentiated, as individuals can doubt their own performance of a behavior even though they believe that a particular course of action will result in certain outcomes (Bandura, 1977). Likewise, people may have confidence in their ability to perform certain behaviors without being convinced it will lead to desirable outcomes.

Generalizability

The concept of SE relates to confidence for performing specific behaviors in specific situations and contexts (Bandura, 1997). Complex behaviors involve multiple tasks with separate efficacy beliefs and expectations, and great sense of efficacy for one activity or behavior does not necessarily transfer to high efficacy in other activities or behaviors (Bandura, 1997). For instance, enhancing SE and physiological parameters for cycling does not necessarily transfer to higher SE and improved functional performance of activities of daily living. However, when behaviors or situations share crucial features and require similar skills and functions, perceived efficacy may generalize from one behavior or situation to other (Bandura, 1977, 1997).

SE – multiple behavior sets and phases of behavior change

Maddux (1995) suggests that SE can be divided into two components, and whereas task SE is an individual's confidence for performing elemental aspects of behavior, coping SE is an individual’s confidence for performing the elemental aspects of behavior in the face of challenges or barriers. Different types of SE may serve different purposes depending on the activity or behavior involved, and this differentiation seems to be particularity relevant to exercise (e.g., Blanchard, Rodgers, Courneya, Daub, & Knapik, 2002; Maddux, 1995; McAuley, et al., 2003). In addition to these two SE components, Rodgers et al. (2008) included a subtype of coping SE - scheduling SE. They argued that an important aspect of exercising regularly is to manage one’s schedule. Maddux (1995) also noted the importance of regular performance of elemental behaviors and scheduling in order to adhere to regular exercise programs, and how this is different from the performance of the exercise itself. The Multidimensional Self-Efficacy for Exercise Scale (MSES) for assessing the three types of SE, was found to have good reliability and validity for all three 3 factors (Rodgers, et al., 2008).

SE could, however, also be organized into different phases of behavior change. Schwarzer and Renner (2000) relate the motivational phase of “action SE” to behavior intention and initiation, and the self-regulating and volitional phase of “coping SE” to behavior adherence over time. A number of studies have shown that the specific type of SE is relevant to changes in adherence as people proceed from initiation to maintenance, including lapse and relapse (e.g. Luszczynska & Tryburcy, 2008).

Intention to initiate exercise and exercise adherence are probably under the influence of different dimensions of SE (Rodgers & Sullivan, 2001). Thus the influence of task, coping, and scheduling SE may differ depending on the stage of behavior change. Task SE might be more important in behavior intention and initiation, whereas coping and scheduling SE might exert a stronger influence on behavior maintenance (Rodgers & Sullivan, 2001). The impact of the various components of SE on different populations may also differ, and few, if any, have considered these components in patients with COPD.

Sources of SE

Bandura argued that there are both behavioral and cognitive influences upon perceived SE, and people’s efficacy beliefs are developed primarily by four sources of information: enactive mastery experience, vicarious experience, verbal persuasion, and physiological/affective states (Bandura, 1977, 1997). Mastery experience is the strongest source of SE information, and whereas SE is increased by successful performances, experience of failure undermine SE (Bandura, 1977, 1997). Factors such as pre-existing knowledge, task-difficulty, effort expenditure, amount of external aid, and course of goal attainment may influence the extent to which people will alter their perceived efficacy through mastery experiences (Bandura, 1997). Vicarious experiences, in which participants observe other people perform activities and behaviors successfully, may increase the participants’ belief that they also possess the capabilities to master comparative activities. However, it is of major importance that the observer is able to believe in and identify him/herself to the (vicarious) person, as well as to the behavior or activity performed (Bandura, 1997). Verbal persuasion is a third source of SE that may bolster an individual’s confidence, but the persuasive person must come across as attractive, trustworthy, and as a source of expertise. The last source of SE, physiological/affective states, may be especially relevant in domains that involve physical accomplishments, health functioning, and coping with stressors. Inefficacious control may generate stress through anticipatory self-arousal. People can actually arouse themselves to elevated levels of stress through the buildup of aversive thoughts about their own inabilities to cope with these stress reactions, and thus the very dysfunction they fear may occur (Bandura, 1997).

Efficacy beliefs

A positive outcome to new challenges and a general sense of personal efficacy, may initially determine adoption, effort, and persistence when facing perceived barriers. People with strong efficacy beliefs are able to withstand failures associated with mastering complex tasks and are more likely to persist in their effort with difficult tasks (Bandura, 1997). In contrast, people with lower efficacy beliefs tend to avoid difficult behaviors, find it hard to motivate themselves, reduce their effort, and give up easily when facing difficulties (Bandura, 1997). Individuals with lower efficacy beliefs may even avoid difficult behaviors they actually could have performed successfully and therefore miss out on a strong and positive mastery experience. Consequently, SE may play a part in determining which activities or situations individuals will perform or avoid. Whereas greater SE can promote the enactment of useful coping strategies, lower SE may result in avoidance (Bourbeau, et al., 2004)**.** Thus, the development of interventions to promote enactment of useful coping strategies could decrease functional disability.

Efficacy beliefs and Exercise

The functional limitations associated with a chronic disease may relate more to the beliefs of capability rather than the degree of actual physical impairment (Bandura, 1997). Exercise can be an effective intervention to break the vicious cycle of dyspnea, inactivity, and deconditioning, and may therefore be important to prevent disability and functional impairment (Whaley, et al., 2006). In general, people who report exercising more also report higher SE, and those with higher SE persist longer with exercise programs, especially in the face of challenges (Bandura, 1997; Bandura & Cervone, 1986; McAuley, et al., 2003; Rodgers, et al., 2008)**.** McAuley et al. (2003) found SE to be an important predictor of long term exercise adherence in older adults (mean age 66 years old), and the same relation is found in people with COPD (Bourbeau, et al., 2004). Indeed, the association of SE to exercise behavior seems to increase with age (Schwarzer & Renner, 2000) and chronic disease (Luszczynska & Tryburcy, 2008), suggesting that SE for exercise is particularly important for elderly persons with chronic diseases. This is also supported by Kaplan, Ries, Prewitt, & Eakin (1994) who noted that the level of SE is an important predictor of success in PR. There is some increasing evidence, however, that SE for exercise may differ between men and women, and that women may have lower confidence for exercising than men (Blanchard, et al., 2002).

Efficacy beliefs and breathing management

Most patients with COPD experience dyspnea or shortness of breath with physical activity, and therefore often lack confidence for avoiding breathing difficulty while engaging in activities, however minimal the physical demand may be (Scherer & Schmieder, 1996). A slow decrease in daily activity level, which may result in limited independent functioning and decreased quality of life, is often seen as a consequence of this fear for dyspnea (Agle & Baum, 1977; Eakin, et al., 1992), and lack of confidence (Wigal, Creer, & Kotses, 1991).

Pulmonary Rehabilitation

PR programs can be important to improve individual's confidence for exercise and ability to manage or avoid breathing difficulties (Bourbeau, 2004; Scherer & Schmieder, 1996). Ewart (1989) even found SE judgments to be a greater predictor of exercise compliance (duration of exercise) than functional evaluation. A sense of SE can develop as the patient learns to integrate new skills (behavior change), and successfully perform these skills in various situations (Bourbeau, 2004). Atkins, Kaplan, Timms, Reinsch, & Lofback (1984) showed that cognitive and behavioral strategies, as part of a self-management program, were useful for motivation and maintenance of walking in patients with moderate to severe COPD. The performance of a CPET is an integral part of PR programs. However, little attention has been given to the effects of exercise testing on psychological factors (i.e. SE for exercise, SE for breathing management, anxiety), and how the test and these factors may influence confidence and motivation for PR participation.

Cardiopulmonary Exercise Test

A CPET is the main activity during the patient's initial visit to the PR program. The patient may place great value on the results and experience of the test, and even though improvements in confidence for exercise and breathing management is not the primary function of the CPET, these may influence and affect further participation in the PR program. In the event that circumstances are made ideal and participation in a CPET creates a successful experience, it may reinforce expectations of self-competency and serve as a source of SE. Likewise a negative experience may undermine SE and add to the perceived barrier to exercise. Therefore, the test's impact on the individual's well-being and SE may be important in the formation of efficacy expectations to exercise and management of breathing difficulties in the PR program.

CPET and the multiple components of SE

Confidence for performance of elemental tasks of exercise may be lower in elderly and patients with chronic diseases compared to young and healthy adults (i.e., decreased exercise capacity because of age and/or disease, unfamiliarity with exercise and/or exercise equipment, greater fear of new and challenging situations, and greater fear of pains and injuries). Bourbeau (2004) found COPD patients to have decreased task SE at the initiation of PR, but the efficacy beliefs increased with persistence and mastery experience of the behavior modifications. The CPET, which occur at initiation of behavior change, may influence the individual's confidence for performing the elemental task of i.e. treadmill walking (i.e. without holding handrails, keep up with speed/grade changes) or ergometer cycling (i.e. keep pedaling speed, even with increasing tension).

However, how confident individuals' feel about performing these elemental tasks may be greatly influenced by how well they are able to cope with various barriers when performing the tasks (i.e. discomfort of breathing through mouthpiece, wearing a noseclip, general breathing discomfort, leg discomfort, seat discomfort, pains, and anxiety). A COPD patient's confidence for managing breathing difficulty during exercise may relate to their ability to cope with discomforts. Thus, an increased belief in the ability to overcome breathing discomfort may be associated with greater confidence for performing exercise.

Confidence for scheduling can also be a great barrier to exercise. However, a change in confidence for scheduling probably occur over time and as the CPET is a one-time occurrence, it is less likely to influence an individual's confidence for managing one's time. Still, if the CPET creates a successful experience, it may convince the individual that the task are not so challenging that it cannot be incorporated regularly into the participant's life. Scheduling SE are probably more important in young and healthy adults though, who are still working and have more regular social- and family commitments.

CPET and sources of SE

Gradual familiarization and appropriate challenge is important when trying to encourage people to adopt exercise activities for which they most likely lack confidence (Ewart, 1989). If the CPET starts too abrupt or is experienced as too challenging, SE may be undermined rather than enhanced. Thus, the choice of exercise modality and test protocol is important to appropriately challenge COPD patients so that SE can be enhanced through a successful mastery experience. The use of vicarious experiences, where a patient watches another patient successfully perform or master a CPET he or she can identify with, could potentially be a great source for enhancing confidence. Practically this would be very difficult as comparable, realistic, and believable comparisons would be hard to create for each patient. Standardized verbal persuasion and encouragements before, during, and after the CPET is also important because it can influence an individual's motivation and efficacy expectations. Manipulation of positive and negative feedback on performance, regardless of actual performance, altered efficacy differently in patients with lower and higher SE beliefs after myocardial infarction (MI) (Bandura & Cervone, 1986). Whereas patients with higher SE worked even harder to accomplish task successfully after a manipulated "failure experience", people with lower SE became less involved (Bandura & Cervone, 1986).

COPD patients may perceive the CPET as threatening due to the unfamiliarity of exercise and the likelihood of experiencing shortness of breath (Eakin, et al., 1992). Thus, the confidence for exercise may be altered by negative affective experiences like anxiety (Ewart, 1995). The prevalence of anxiety is found to be high in COPD patients, independent of disease severity, compared to healthy controls (Brenes, 2003; Di Marco, et al., 2006), and is worse in women than men (Di Marco, et al., 2006). A differentiation can be made between trait anxiety (i.e. a stable behavioral tendency to experience anxiety) and state anxiety (i.e. a mode state, often short-term or provoked by a specific situation) (Spielberger, 1983). People with high trait anxiety are more likely to perceive stressful situations to be threatening and respond to such situations with elevations of state anxiety (Spielberger, 1983). Carlyle (2006) supported this in her master thesis research in cardiac patients, where she also found higher levels of anxiety before exercise testing to be associated with lower peak exercise work load and peak HR.

According to Bandura (1977, 1997) people fear and tend to avoid threatening situations they believe exceed their coping skills. Potential threats activate fear largely through cognitive self-arousal, as people can arouse themselves to elevated levels of anxiety that far exceed the actual threat. Thus, prior to CPET, individuals may experience strong physiological reactions (Maddux, 1995) and activation of the autonomic nervous system (i.e. elevated heart rate, increased blood pressure, shallow and fast breathing) (Spielberger, 1983). COPD patients may interpret the sensations of breathlessness and hyperventilation as more dangerous than they really are and this may result in a spiral of increased fear, physiological arousal, and breathlessness. However, successfully performing an activity (i.e., a CPET) that is subjectively perceived as fearful, but are relatively safe, may enhance SE through enactive mastery (Bandura, 1977, 1997).

Cardiopulmonary Exercise Test and Self-Efficacy

Little research has been conducted on the relation between SE and CPET. Ewart et al. (1983) performed treadmill testing after MI and found an immediate increase in SE for activities similar to the treadmill exercise (e.g. running, walking, climbing), especially in people who underestimated their physical capabilities. SE for activities dissimilar to walking (i.e., sexual intercourse and arm activities) did not increase immediately after the test, but did so after a positive feedback talk with the nurse and physician. Interestingly, they also found the change in SE scores and SE appraisals to better predict intensity and duration of subsequent home activity levels than functional exercise evaluation. However, these results were only true for most of the patients. The increase was absent in a small sub-group of patients who experienced exercise-induced chest pain (angina) during the test. This subgroup is possibly more similar to COPD patients than the general MI patient, and the dyspnea experienced by COPD patients may influence SE in a similar manner as chest pain influenced these MI patients. In support of this, Oka et al. (2005) found no improvements in SE for walking, climbing, lifting, and general activity when they assessed the influence of SE on a single treadmill test in a group of mild to moderate heart failure patients. Heart failure patients may also be more comparable (i.e. with regards to age and exercise capacity) to COPD patients than general MI patients.

Exercise modality and Self-Efficacy

Walking is probably a more familiar activity than cycling to most patients with COPD. The overall goal of PR is to improve functional capacity in performing activities of daily living (ADL), and muscle recruitment and elemental movements of walking may be more similar to ADLs than cycling. Thus, if a COPD patient successfully masters the experience of the CPET, the mastery experience may enhance the individual’s confidence for performing other similar activities in the future (i.e., walking during PR, and ADLs). On the contrary, if the patient perceives the CPET as a failure this could undermine confidence for performing similar activities in the future and may serve as an additional barrier to perform the activities (i.e. walking, PR).

However, walking on the treadmill is different from regular walking, where you are able to set your own pace and take breaks. Thus, treadmill walking may initially be perceived as more challenging than cycling. The lack of control patients have over stopping the test whenever the exercise is perceived as uncomfortable, and not being able to hold on the handrails (as it decreases the accuracy of the test), may increase the patients fear and increase dyspnea (hyperventilation). Decreased muscle strength, which is often seen especially in women with COPD, may influence the level and perception of balance on the treadmill, but it may also interfere with the performance of cycling. Due to early muscle fatigue in the quadriceps the patient may experience marked dyspnea and feel challenged in order to keep pedaling. If a patient perceives a test as challenging, but is able to perform the test, the successful mastery experience is likely to generate even greater confidence for exercise. However, if the test is too challenging, confidence may be undermined. Thus, finding the exercise mode and test protocol that can challenge the patient at an appropriate level, are likely to be most successful for enhancing SE for exercise and SE for breathing management.

At the current time, the research is limited regarding what kind of influence the CPET can have on COPD patient's confidence for exercise and breathing management, and thus there is no first choice for either exercise mode or protocol. Women, who appear to have lower confidence for exercise (Blanchard, et al., 2002) and experience more anxiety than men (Di Marco, et al., 2006), can arouse themselves into a spiral of stress, physiological arousal, and dyspnea, and thus, the CPET may have a greater impact (both positive and negative) on women.

There is clearly a great need for further research in this area, and the purpose of this study is to examine the physiological and psychological differences associated with exercise testing on the cycle verses the treadmill. Special interest will be given to the differences between men and women. Thus, the primary question is: Are the physiological and psychological responses to linear work rate treadmill and cycle ergometer exercise different in men and women with COPD? Based on the information above, is it hypothesized that women will experience greater dyspnea than men, regardless of exercise modality. However, it is further believed that women may experience greater dyspnea on the cycle ergometer than the treadmill.

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Chapter 2

METHODS

The Centre for Lung Health

The Centre for Lung Health (CFLH) offers The *Breathe Easy Program,* which is an outpatient PR program for people diagnosed with chronic lung disease. The program is designed to help participants manage their chronic lung disease through supervised exercise classes and education sessions on numbers of related topics such as understanding and coping with lung disease, proper use of respiratory medications, breathing management, and nutrition. The supervised exercise sessions are tailored to the individual's needs and capabilities, and incorporate the use of a variety of exercise equipments including treadmills, stationary bikes, rubber bands and handheld weights. The program runs for 6 weeks (3 sessions per week) or 8 weeks (2 sessions per week).

Admission to the program requires referral by a physician, including a full pulmonary function test (PFT). Prior to admission, all potential clients must perform a CPET, and the CPET is currently performed on a treadmill. Based on the patient history, the physicians choose the most appropriate out of six treadmill cardiopulmonary exercise protocols. The CPET assess safety of exercise, exercise capacity, and limitations to exercise. The results from the pre-program tests are compared to the results of a similar post-program tests, and this is included as part of the outcome evaluation.

Participants

Eligible participants included those who were referred by a physician to the CFLH with a diagnosis of COPD. Subjects were excluded if they had recent respiratory exacerbation, unstable cardiac disease, orthopedic limitations (that would hinder treadmill walking and/or cycling), required supplemental oxygen, and/or if they for some reason were unable to follow instructions and answer questionnaires (i.e., language barriers). Participants were recruited prior to their pre-program assessment, either on the phone (in relation to booking them to the program and scheduling their exercise test, or after the secretary had already scheduled them for an exercise test) or at the Centre while they were waiting for their exercise test.

Out of 24 eligible participants, 22 patients gave written consent to participate in the study. One male did not want to participate in the study because of time commitments and one female did not want to participate due to nervousness. Two patients were subsequently excluded from the analysis because a male participant suffered from hip pain after the cycle test and was unable to return for the second assessments, and a lady was excluded because of technical difficulties with the communication between the cycle ergometer and the metabolic cart. Overall 20 patients, 12 males and 8 females, with COPD (FEV_1% 57.2±19.112) completed the two exercise assessments and were included in the analysis. Seven out of the 20 participants had previous experience with an exercise test. However, none of the participants had previous experience with a cardiopulmonary exercise test. The characteristic demographics are presented in Table 1. The study was approved by the University of Alberta Health Research Ethics board (Biomedical Panel).

Instruments

Patient demographics.

Information was gathered from the database/doctors chart at the CFLH, or retrieved by asking the patient in person.

Cardiopulmonary Exercise Test.

Anthropometric data.

Weight (kg) and height (cm) were measured with stationary scale/measuring tape in the pre-assessment area, and all measures of circumference (hip, waist, and mid-thigh) were measured by measuring tape in cm. Resting blood pressures (BP, mmHg) was measured manually by blood pressure cuff and barometer, whereas resting HR (bpm) and oxygen saturation

(SpO_2, %) were measured with a portable oximeter (Nellcor N20, Pleasanton, California).

Metabolic exercise testing.

The incremental exercise tests were performed on an electromagnetically-braked cycle ergometer (Ergoselect 200P; Ergoline GmbH, Blitz, Germany) and a treadmill (TMX425C by Full Vision Inc, Newton, Kansas, USA). Spirometry and IC maneuvers, as well as breath-by-breath measurements (minute ventilation (V_E), tidal volume (V_T), respiratory rate (RR), oxygen consumption (VO_2), carbon dioxide production (VCO_2), end-tidal oxygen ($P_{ET}O_2$) and carbon dioxide partial pressure ($P_{ET}CO_2$)) were collected by cardiopulmonary exercise testing system (Vmax Spectra V29 System; SensorMedics, Yorba Linda, CA). Subjects were monitored by 12-lead ECG (Cardiosoft; SensorMedics, Yorba Linda, CA) and pulse oximetry with finger probe measurements. BP was measured by manual blood pressure cuff and barometer. Breathing- and leg discomfort were measured with the 10-point Borg category-ratio scale (Borg, 1982), where zero represented “no breathing (leg) discomfort” and 10 represented “maximal breathing (leg) discomfort”. The participants’ feeling state (“How are you feeling in general right now”), were measured with the Feeling Scale, from + 5 to -5 (Rejeski, Best, Griffith, & Kenney, 1987).

Questionnaires.

Questionnaire packet 1.

The Multidimentional Self-Efficacy for Exercise Scale (MSES), the Feeling Scale (FS), the State-Trait Anxiety Inventory (STAI) – state, and the Activation-Deactivation Adjective Check List (AD ACL) was included in the questionnaire packet given out before and after each CPET.

The Multidimentional Self-Efficacy for Exercise Scale (MSES) by Rodgers et al., (2008) is an instrument that assess three SE domains believed to be important in supporting sustained physical exercise behavior – SE for task (confidence for performing the elemental behavior), coping (confidence for overcoming barriers), and scheduling (confidence for managing one’s time). The scale consists of 9 statements, 3 for each domain. The self-efficacy for exercise is rated on a continuous confidence scale from 0% (no confidence) to 100% (complete confidence). Rodgers et al. (2008) found the scale to be reliable in assessing task, coping, and scheduling SE for exercise, and found a robust relationship with exercise behavior in students, community adults, and women respectively.

The Feeling Scale by Rejeski et al. (1987) is a tool that can be used to assess affective responses during exercise by evaluating the core of emotions: good versus bad (Hardy & Rejeski, 1989). The scale is presented as an 11-point bipolar good/bad format, ranging from +5 to -5, with the following verbal anchors: +5 very good, +3 good, +1 fairly good, 0 neutral, -1 fairly bad, -3 bad, and -5 very bad (Hardy & Rejeski, 1989).

The State-Trait Anxiety Inventory (STAI) by Spielberger (1983) is an instrument to measure state and trait anxiety. The STAI trait anxiety scale consist of 20 items where people rate how they feel on a four-point scale ranging from 1 (almost never) to 4 (almost always). The STAI state anxiety scale consist of 20 items where people rate the intensity of how they feel at that particular moment using a four-point scale from 1 (not at all) to 4 (very much so). The correlation between the two scales is found to be quite strong because individuals with high trait anxiety tend to show more state anxiety in situations they are trait anxious about.

The Activation-Deactivation Adjective Check List (AD ACL) by Thayer (1967) is a multidimensional test of various arousal states. The AD ACL contains 20 items of energetic and tense arousal, split up into four subscales: energy, tiredness, tension, and calmness. People rate how they feel right at that moment using a four-point scale including definitely feel, feel slightly, cannot decide, and definitely do not feel.

Questionnaire packet 2.

STAI-state, STAI-trait, Godin Leisure-Time Exercise Questionnaire, and the COPD Self-Efficacy Scale (CSES) are included in the questionnaire packet all participants are given after the second test to bring home.

The Godin Leisure-Time Exercise Questionnaire by Godin & Shephard (1997) is a four-item query for people to rate their usual leisure-time habits. 1) "During a typical 7-day period (a week), how many times on the average do you do the following kinds of exercise for more than 15 minutes during your free time", a) strenuous exercise, b) moderate exercise, and c) mild exercise 2) "During a typical 7-day period (a week), in your leisure time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)? I) often II) sometimes, or III) never/rarely.

The COPD Self-Efficacy Scale (CSES) by Wigel et al., (1991) is an instrument made up of 34-itmes arranged in a five-factor structure including negative affect, intense emotional arousal, physical exertion, weather/environmental, and behavioral risk factors. The purpose of the scale is to assess which situations individuals with COPD experience decreased self-efficacy. The patients are instructed to determine how confident they are about managing breathing difficulty or avoiding breathing difficulty in the situations described in the 34-items, and each item will be rated on a 5-point scale: a) = very confident, b) pretty confident, c) = somewhat confident, d) not very confident, and e) not at all confident. Wigal et al. (1991) found the CSES to have good rest-retest reliability (r=0.77), excellent internal consistency (Cronbach's alpha =0.95).

Procedures

All participants were instructed to continue prescribed medications as normal, but were encouraged to avoid caffeinated coffee/tea and cigarette smoking 2 hours prior to the appointment. Volunteers for the study completed two CPETs at two different visits to the CFLH (mean time apart = 9.7±5.2 days), where one test was performed on a treadmill and one was performed on a cycle ergometer. In randomized order, the participants performed their initial test either on a treadmill (n=13) or a cycle ergometer (n=7).

Patient demographics.

Information about the patient’s age, sex, diagnosis, pulmonary function test (PFT), medications, smoking history, and co-morbidities were retrieved, in addition to information about previous experience with treadmill and/or cycle ergometer exercise, and whether they performed any regular exercise on any of the two modalities. Information about whether they had ever performed an exercise test (“stress test”) before was also collected.

Pre-assessment measurements.

All test preparations and measurements were performed by trained personnel according to the standardized procedures at CFLH. Weight, height, resting BP, HR, and SpO_2 were measured at both visits. Waist, hip – and mid-thigh circumference was measured only at their second visit, as this was not part of the standardized procedures at the CFLH.

Cardiopulmonary Exercise Testing.

Information.

Standardized information was given about the incremental exercise test. All participants were encouraged to walk/cycle for as long as possible, but were informed that the test would end when they felt they could not keep going any longer. Information was also given about the mouthpiece and noseclip, the resting spirometry maneuver, the continuous measurements of ECG, HR, SpO_2 , as well as measurements of BP, IC, breathing- and leg discomfort, and feeling state before, during and the end of the test.

Resting ECG.

As soon as the patients were hooked up to the ECG and were standing on treadmill/sitting on cycle ergometer with arms resting along the side, a resting baseline ECG was printed off and evaluated by the physician.

Spirometry.

Standardized spirometry measures were performed at baseline to position the patients' tidal breathing within the maximal flow volume loop. The maneuvers were performed standing on the treadmill and seated on the cycle ergometer. The patient was holding on to the mouthpiece with one hand and to either the railings on the treadmill or the handlebar on the cycle with the other hand. The patient was asked to take a big breath in followed by exhaling with maximal force for as long as they could. When the patient could not breathe out any more, he/she was encouraged to take a big breath all the way in again. The participants were coached through the whole procedure in order to ensure maximal effort. The procedure was performed prior to both exercise tests.

Baseline measures.

Once the patient was breathing through the mouthpiece with the nose plugged, baseline BP was measured within the first minute, the baseline rating of breathing discomfort, leg discomfort, and feeling state was measured after two minutes, and a baseline IC maneuver was performed after two minutes.

Exercise.

A protocol with increases in work rate every minute was used for both the treadmill and the cycle ergometer. The rate of increasing work was determined from the patient's resting lung function, FEV_1. Increments of 5W min^{-1} were used in patients with $FEV_1 < 1.0L$, and increments of 10W min^{-1} were used in patients with $FEV_1 > 1.0L$, similarly to Hsia et al, 2009**.** However, some patients' protocols were changed to 20W min^{-1} if the physician and technician believed the test otherwise would exceed the recommended test duration of 8 – 12 minutes (Wasserman, et al., 2005). The load was increased until subjects reached symptom limitation or by physician's medical request. Work rate increased automatically on the cycle ergometer. The patients were encouraged, however, to keep pedaling at 60 repetitions per minute (rpm). Comparative increases in workload on the treadmill were achieved through manual adjustments of speed and grade. A constant increase in work rate was approximated through a constant increase in speed (0.2mph) and a curvilinear increase in inclination (rounded to closest 0.5%) each minute. The work rate increments were based on the formulae in Cooper & Storer (2005, page 28): W = 0.1634 * speed * (grade/100) * body weight (kg), thus, the patient's body weight influenced the inclination of the treadmill. Holding on to the handrails on the treadmill was discouraged, especially leaning on and/or gripping tightly on to the handrails. However, several patients were unable to keep balance on the treadmill without resting the hands on the railings. Regardless of performance on the initial CPET, the same work load increments were used for the second test even if a different protocol ideally should be used for the patient to achieve an exercise time of 8 – 12 minutes. This was done in order to evaluate the physiological and psychological parameters at similar work rates throughout the two tests.

Measurements.

ECG and SpO2 values were continuously monitored before and throughout the test, and BP was measured at baseline, every 4 minutes and at peak exercise (unless BP was measured within the last minute of exercise). In certain circumstances BP readings were missed for reasons such as "difficult to hear" or "patients being uncomfortable on the treadmill/cycle so that the technician had to pay full attention to the patient". Recovery BP was measured only on physician's request (i.e. if peak BP was abnormally elevated).

Exertional symptoms.

Standardized information about the Borg category-ratio scale (CRS) was given to all participants prior to the test. The subjects were asked to rate the intensity of their breathing discomfort – the sensation of labored or difficult breathing during exercise, and leg discomfort – the level of leg difficulty/discomfort experienced during exercise, by pointing to the modified Borg CPS (Borg, 1982). Ratings were performed at baseline, every two minutes, at end exercise and 2 minutes into recovery. At the same time points, all participants were instructed to rate "how they feel in general" by pointing to the FS (Rejeski et al., 1987). At end-exercise all subjects were told to specify their reason for termination. They had to choose from the following four alternatives: 1) breathing discomfort, 2) leg discomfort, 3) both, or 4) other.

Tidal flow volume and inspiratory capacity maneuvers.

Flow and volume was recorded continuously during the exercise tests. At rest, every two minutes, at the end of the exercise and two minutes into recovery a tidal volume curve was constructed for each patient, coinciding with the IC measurements. Standardized information about the IC measurements was given to the patients prior to each assessment. The following instructions were given: "at the end of a normal breath out, you take a big breath all the way in". If an exercise IC maneuver was unacceptable (i.e., submaximal effort or anticipatory changes in breathing pattern immediately prior to the IC maneuver), the IC maneuver was repeated. However, no more than two IC maneuvers were performed in a row, and unacceptable maneuvers were excluded from the analysis. Expiratory flow limitation (EFL), operating lung volumes (EELV) and dynamic hyperinflation (DH) was detected by comparing the tidal flow volume loops to the maximal flow volume loops. Also, with the assumption that TLC did not change with exercise, the changes in IC reflected changes in EELV (EELV = TLC – IC). Thus, a decrease in IC reflected an increase in EELV, and accordingly the extent of DH. The IC's and the exertional symptoms were measured at alternating minutes so they would not interfere with each other. The measurements were performed right at the change into a new work stage in order to reflect back on the work stage just finished without interfering with the 30sec average sampling of ventilatory parameters.

Ventilatory data.

Breath-by-breath measurements of ventilatory parameters were collected in 30sec averages. The average of last 30sec for each workload was used in the analysis, and peak values were recorded as the average of the last 30sec of the last completed workstage.

Encouragements.

Encouragements such as “you are doing well”, “good job”, and “everything looks good” were given during the tests. The participants did not get any additional information about how they did until after they completed the post questionnaire after the second CPET.

Calibration.

Treadmill (speed and grade) and cycle ergometer (power outputs) were calibrated for accuracy prior to the study. Airflow was calibrated once for up to six tests and gas concentrations were calibrated before and after each test.

Questionnaires

Questionnaire packet 1.

All participants were asked to complete the MSES, FS, STAI-state, and AD ACL before and after both exercise tests. A researcher was available in case the participants had questions about the questionnaires, but they were encouraged to complete the questionnaire on their own (also if they had friends or relatives accompanying them to the appointment).

Questionnaire packet 2.

All participants were given the STAI-state, STAI-trait, Godin Leisure-Time Exercise Questionnaire, and CSES to complete at home, in their quiet resting time, a couple of days after the second CPET. They were instructed to return the questionnaire either by mail, in a pre-paid envelope, or by bringing it back to the centre if their program started within the next few days.

Analysis

To examine the changes in physiological responses (i.e. main metabolic, ventilatory, and symptomatic variables listed above), repeated measures ANOVAs were conducted. Sex (men/women) was the between-subjects factor, whereas modality (treadmill/cycle) and work stage were the within-subject factors. Because the patients had different end stages and therefore number of scores, the data were grouped and analyzed as both absolute (baseline, work stage 1, 2, 3, and peak exercise) and relative work stages (40%, 80%, and 100% of VO_{2peak}). The order of the exercise modality was disregarded in the analysis.

To examine the changes in the following dependent variables (i.e., SE, FS, state-anxiety, and arousal states), doubly repeated measures ANOVAs were conducted. Sex (men/women) and exercise modality (whether test one was a cycle or a treadmill) were between-subject factors. Test (test one versus test two) and time (pre versus post assessment) were within-subject factors, both treated as repeated measures. As a result, the following analysis were performed: Sex (male/female) x Test (1 or 2) x Modality (treadmill/cycle) x Time (pre/post). Separate analyses were conducted for each of task, coping, and scheduling SE, and for the four factors of arousal states.

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Chapter 3

RESULTS

Patient characteristics

As we did not control for height, the men were significantly taller than the women ($\eta^2=0.303$, $p<0.02$). There were no other significant differences in patient characteristics between men and women.

Table 3-1: Patient characteristics

	Total	Male (M)	Female (F)	Significant differences (M vs F)
n	20	12	8	
Age	65±11	66±12	62±8	ns
Height, m	1.68±0.07	1.71±0.06	1.63±0.07	p<0.02
Weight, kg	79.3±18.5	84.2±16.9	71.9±19.5	ns
BMI, kg/m^2	28.0±6.5	28.7±5.8	27.0±7.8	ns
Waist circumference, cm	101.7±18.3	107.0±14.9	93.7±20.9	ns
Hip circumference, cm	106.8±11.4	105.9±7.7	108.2±16.0	ns
Mid-thigh circumference, cm	48.7±8.4	50.7±4.2	45.7±12.0	ns

ns = non-significant

Consequently, as men were significantly taller than the women, significant differences were observed between men and women for lung volumes. Men had greater VC ($\eta^2=0.422$, $p<0.01$) and TLC ($\eta^2=0.499$, $p<0.01$). Correspondingly, a significant difference was also seen for FVC ($\eta^2=0.265$, $p<0.05$). There were no significant differences in FEV_1, FEV_1/FVC, or diffusion capacity. A significant difference was seen between men and women who were still smoking ($\eta^2=0.339$, $p<0.02$). Whereas 4 of 8 women (50%) were still smoking, none of the male participants were smokers.

Table 3-2: Lung function

Spirometric values	Total	Male	Female	Significant differences (M vs F)
FEV_1,L	1.56±0.52	1.64±0.60	1.45±0.36	ns
FEV_1, %	57.2±19.1	55.7±21.7	59.4±15.6	ns
FVC, L	3.22±8.86	3.55±0.90	2.74±0.64	$p<0.05$
FVC, %	90.8±22.7	92.8±26.8	87.6±15.8	ns
FEV_1/FVC	49.7±13.0	46.3±9.9	54.8±15.9	ns
Lung Volumes				
VC, L	3.2±1	3.7±1.0	2.5±0.5	$p<0.01$
VC, %	85.5±20.1	89.6±23.7	79.3±11.9	ns
TLC, L	6.9±1.7	7.8±1.2	5.5±1.5	$p<0.01$
TLC, %	121.0±24.6	128.8±22.7	109.4±24.0	ns
RV, L	3.6±1.4	4.1±1.4	3.0±1.2	ns
RV, %	171.2±61.7	180.5±67.0	157.1±53.7	ns
Diffusing capacity				
DLCO, ml/mmHg/min	15.8±5.5	17.0±6.1	14.0±4.2	ns
DLCO, %	68.6±21.1	70.3±22.3	66.0±19.8	ns
VA, L	4.7±1.2	5.4±1.1	3.7±0.6	$p<0.01$
DLCO/VA	3.4±0.8	3.1±0.8	3.7±0.8	ns
Medical Research Counsil (MRC) scale (1-5)	3.1±0.9	3.4±0.7	2.7±1.1	$p=0.064$
Smoking history, pack/years	48.0±16.1	51.2±18.8	43.1±10.3	ns
Smokers, n	4	0	4	$p<0.05$

ns = non-significant

No observed differences were noted in relation to exercise duration (test 1 vs test 2, treadmill vs cycle, men versus women, or any interactions between the aforementioned).

Table 3-3: Exercise duration (in minutes) for CPET 1 and CPET 2 (treadmill vs cycle).

	Test 1			Test 2			Total
	Treadmill	Cycle	Total	Cycle	Treadmill	Total	
Male	8.6 (3.3)	6.0 (2.3)	7.7 (3.2)	7.6 (2.3)	5.4 (3.2)	6.8 (2.7)	
Female	6.9 (1.9)	7.0 (0.0)	6.9 (1.5)	5.8 (1.9)	8.7 (0.6)	6.9 (2.1)	
Total	7.9 (2.9)	6.4 (1.7)	7.4 (2.6)	6.9 (2.3)	6.8 (2.9)	6.9 (2.4)	
Treadmill							7.5 (2.9)
Cycle							6.7 (2.1)
Total							7.1 (2.5)

Table 3-4: Reason for CPET termination

Reason for termination		Breathing discomfort	Leg discomfort	Both	Other
Male	Cycle CPET	4	3	4	1
Male	Treadmill CPET	5	4	2	1
Female	Cycle CPET	1	4	2	1
Female	Treadmill CPET	2	1	3	2
Total	Cycle CPET	5	7	6	2
Total	Treadmill CPET	7	5	5	3

Power output

The calculated linear treadmill protocol was chosen to approximate a power output profile on the treadmill similar to the linear power output profile seen with the cycle ergometer. As expected with incremental exercise, a significant main effect for work stage was observed (F(4,15)=90.150, p<0.01,

$\eta^2=0.960$ (absolute work stages) and $F(2,16)=66.099$, $p<0.01$, $\eta^2=0.892$ (relative work stages)). An interaction for work stage and modality was also shown for both absolute ($F(2,17)=4.171$, $p<0.05$, $\eta^2=0.329$) and relative ($F(2,16)=4.825$, $p<0.05$, $\eta^2=0.376$) work stages, where treadmill exercise resulted in greater maximal power output than cycle exercise at peak exercise. There was no significant between-sex differences, as both men and women achieved greater power output at peak exercise with treadmill exercise compared to cycle exercise.

Table 3-5: Power output (watts) at absolute work stages

Power output, Watts	Baseline M (SD)		Work stage 1 M (SD)		Work stage 2 M (SD)		Work stage 3 M (SD)		Peak M (SD)	
	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread
Male	0.0 (0.0)	0.0 (0.0)	9.6 (1.4)	9.6 (1.4)	19.2 (2.9)	19.2 (2.9)	28.8 (4.3)	28.8 (4.3)	70.8 (29.1)	75.8 (41.0)
Female	0.0 (0.0)	0.0 (0.0)	8.8 (2.3)	9.4 (1.8)	17.5 (4.6)	18.8 (3.5)	28.1 (5.3)	28.1 (5.3)	69.4 (28.6)	88.1 (40.9)
Total	0.0 (0.0)	0.0 (0.0)	9.3 (1.8)	9.5 (1.5)	18.5 (3.7)	19.0 (3.1)	28.5 (4.6)	28.5 (4.6)	70.3 (28.1)	80.8 (40.3)

Tread = treadmill

Table 3-6: Power output (watts) at relative work stages

Power output, Watts	40% VO_{2peak} M (SD)		80% VO_{2peak} M (SD)		100% VO_{2peak} M (SD)	
	Cycle	Treadmill	Cycle	Treadmill	Cycle	Treadmill
Male	8.3 (5.8)	10.0 (11.3)	47.9 (24.3)	48.3 (32.4)	70.8 (29.1)	75.0 (40.6)
Female	12.9 (9.5)	15.0 (8.7)	52.1 (26.1)	58.6 (29.7)	76.4 (28.7)	96.4 (36.1)
Total	10.0 (7.4)	11.8 (10.4)	49.5 (24.3)	52.1 (31.0)	72.9 (28.3)	82.9 (39.4)

Oxygen uptake (VO_2)

Similarly to the observed findings for power output, a significant main effect for absolute work stages ($F(4,15)=90.150$, $p<0.01$, $\eta^2=0.960$) and relative work stages were observed ($F(2,16)=68.858$, $p<0.01$, $\eta^2=0.896$) for VO_2. There was a significant main effect for modality ($F(1,18)=18.966$, $p<0.01$, $\eta^2=0.513$ for absolute work stages and F(1,17)=12.239, $p<0.01$, $\eta^2=0.419$ for relative work stages), where VO_2 was greater with treadmill exercise compared to cycle exercise all throughout the test. An interaction between the absolute work stages and modality was observed (F(4,15)=6.755, $p<0.05$, $\eta^2=0.643$), and a greater difference in VO_2 was observed between the modalities at the higher work stages. At the relative work stages this interaction was not significant.

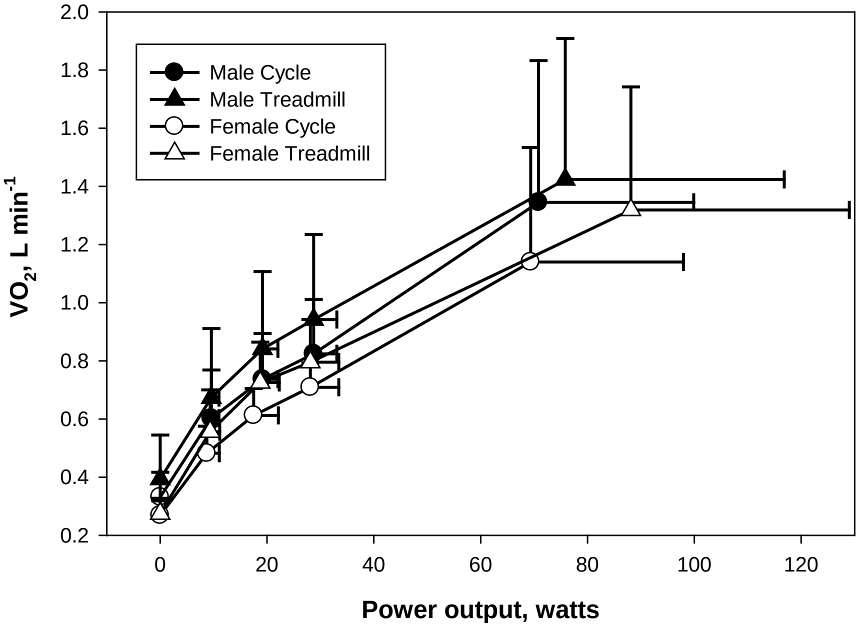

Figure 3-1: Changes in oxygen uptake (VO_2) relative to increases in power output during cycle and treadmill-CPETs. Data are presented for baseline (0 watts), the initial three stages of the CPET and at peak exercise.

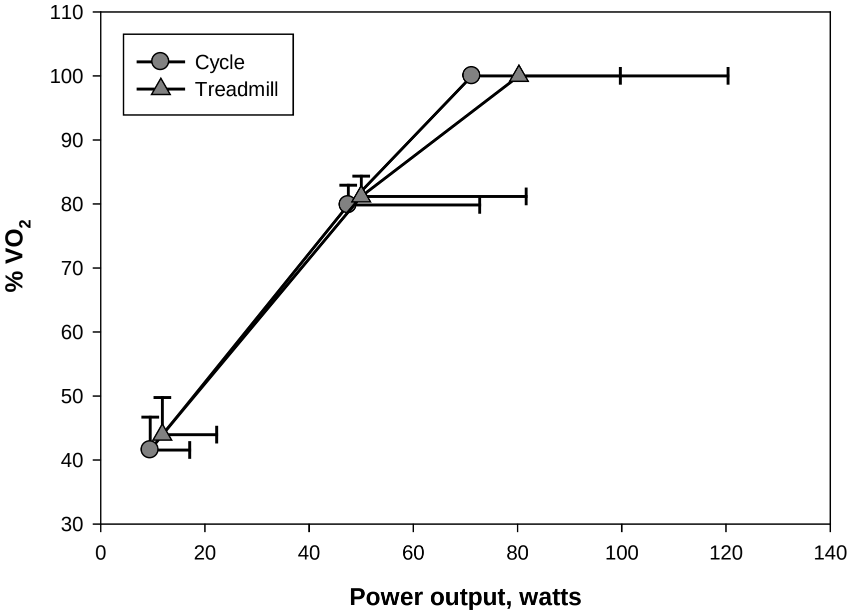

Figure 3-2: Changes in percent of peak oxygen uptake (VO_{2peak}) relative to power output during cycle and treadmill CPET. Data are presented for 40%, 80%, and 100% of VO_{2peak}.

There was no significant between-sex difference observed between the modalities.

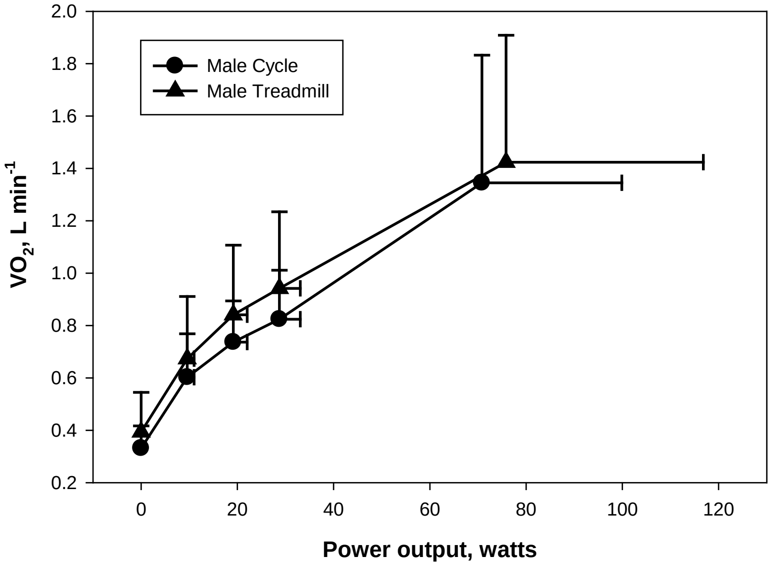

Figure 3-3a: Changes in oxygen uptake (VO$_2$) relative to increases in power output during cycle and treadmill-CPETs in men. Data are presented for baseline (0 watts), the initial three stages of the CPET and at peak exercise

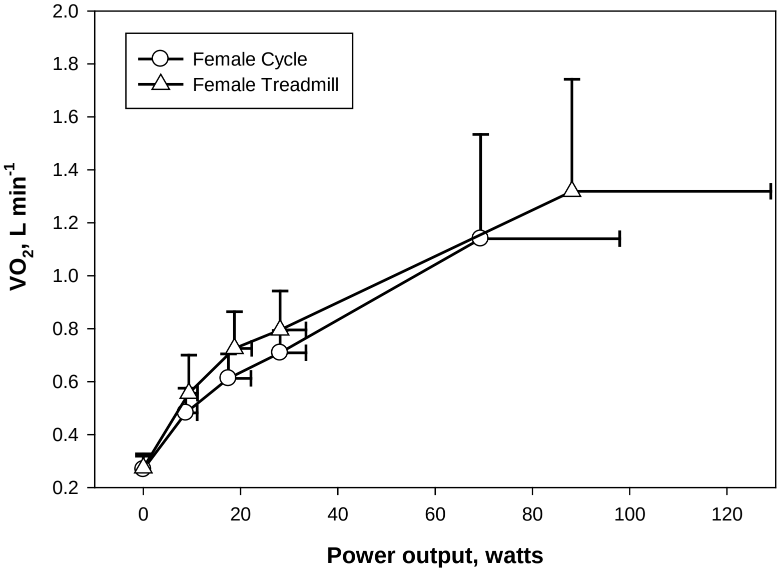

Figure 3-3b: Changes in oxygen uptake (VO2) relative to increases in power output during cycle and treadmill-CPETs in women. Data are presented for baseline (0 watts), the initial three stages of the CPET and at peak exercise

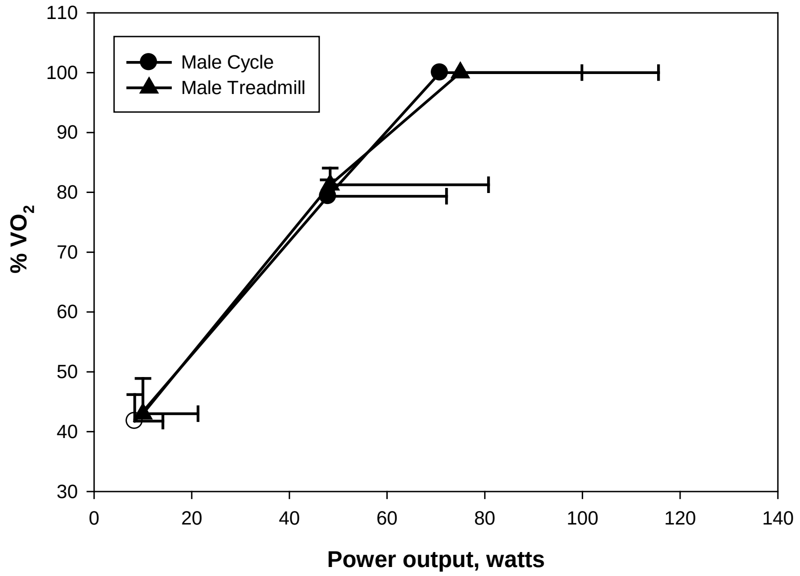

Figure 3-4a: Changes in percent of peak oxygen uptake (VO_{2peak}) relative to power output during cycle and treadmill CPET in men. Data are presented for 40%, 80%, and 100% of VO_{2peak}.

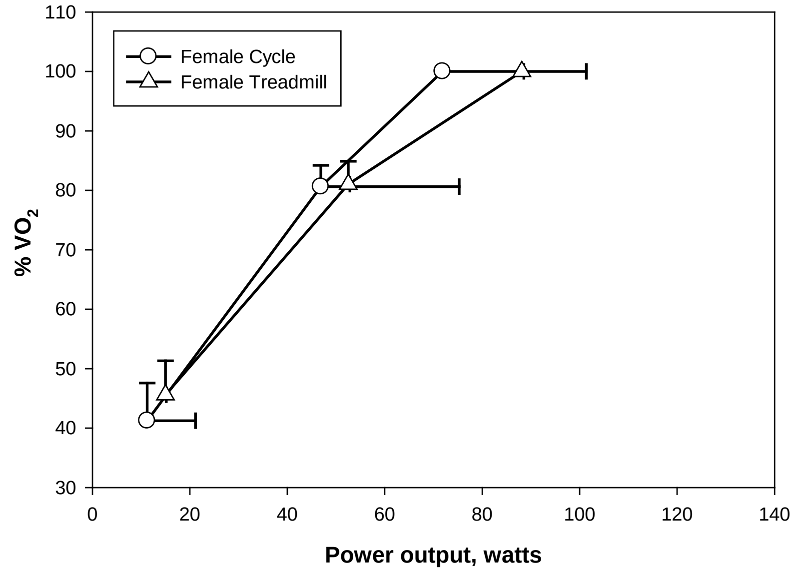

Figure 3-4b: Changes in percent of peak oxygen uptake (VO_{2peak}) relative to power output during cycle and treadmill CPET in women. Data are presented for 40%, 80%, and 100% of VO_{2peak}.

Carbon dioxide production (VCO_2)

A significant main effect was observed for VCO_2 at absolute work stages (F(4,15)=64.408, $p<0.01$, $\eta^2=0.943$) and relative work stages (F(2,16)=48.237, $p<0.01$, $\eta^2=0.858$). However, in contrast to the responses for power output and VO_2, there was no significant effect for modality. A significant interaction was observed for work stage, sex, and modality at the absolute work stages (F(4,15)=4.070, $p<0.02$, $\eta^2=0.520$), where the VCO_2 output at peak exercise was greater with cycle exercise in men and with treadmill walking in women.

Table 3-7: Carbon dioxide production in L min^{-1} (VCO_2) at baseline, work stages 1, 2, and 3, and peak exercise.

VCO_2, L-min^{-1}	Baseline M (SD)		Work stage 1 M (SD)		Work stage 2 M (SD)		Work stage 3 M (SD)		Peak M (SD)	
	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread
Male	0.299 (0.073)	0.329 (0.115)	0.533 (0.135)	0.539 (0.172)	0.671 (0.149)	0.666 (0.205)	0.764 (0.176)	0.753 (0.227)	1.414 (0.579)	1.333 (0.537)
Female	0.230 (0.044)	0.249 (0.054)	0.421 (0.072)	0.464 (0.110)	0.530 (0.063)	0.605 (0.125)	0.637 (0.054)	0.677 (0.141)	1.293 (0.504)	1.376 (0.493)
Total	0.272 (0.071)	0.297 (0.102)	0.488 (0.125)	0.509 (0.152)	0.615 (0.139)	0.642 (0.176)	0.714 (0.152)	0.722 (0.197)	1.366 (0.540)	1.350 (0.507)

Tread = treadmill

Table 3-8: Carbon dioxide production in L min^{-1} (VCO_2) at 40%, 80%, and 100% of VO_{2peak}.

VCO_2, L-min^{-1}	40% VO_{2peak} M (SD)		80% VO_{2peak} M (SD)		100% VO_{2peak} M (SD)	
	Cycle	Treadmill	Cycle	Treadmill	Cycle	Treadmill
Male	0.506 (0.197)	0.493 (0.158)	1.047 (0.407)	0.997 (0.389)	1.414 (0.579)	1.330 (0.535)
Female	0.424 (0.127)	0.508 (0.132)	0.956 (0.300)	1.034 (0.354)	1.369 (0.491)	1.463 (0.461)
Total	0.476 (0.175)	0.499 (0.145)	1.013 (0.365)	1.010 (0.367)	1.398 (0.535)	1.379 (0.500)

Heart rate (HR)

HR increased significantly with incremental exercise (F(4,15)=61.429, $p<0.01$, $\eta^2=0.942$ for absolute work stages, and F(2,16)=58.327, $p<0.01$, $\eta^2=0.879$ for relative work stages), but the increase was not significantly different between the two exercise modalities and/or between sexes.

Table 3-9: Heart rate in beats per minute (HR, bpm) at baseline, work stages 1, 2, and 3, and peak exercise.

HR, bpm	Baseline M (SD)		Work stage 1 M (SD)		Work stage 2 M (SD)		Work stage 3 M (SD)		Peak M (SD)	
	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread
Male	85.6 (20.1)	85.8 (20.1)	93.0 (19.7)	95.1 (19.9)	98.0 (18.7)	98.8 (20.1)	101.1 (19.5)	102.6 (20.1)	119.3 (23.7)	123.4 (26.1)
Female	75.3 (8.8)	79.5 (12.2)	88.9 (9.7)	89.4 (13.2)	93.9 (11.5)	96.4 (14.4)	98.5 (13.3)	100.5 (14.8)	126.8 (11.7)	127.9 (14.3)
Total	81.5 (17.0)	83.3 (17.3)	91.4 (16.3)	92.8 (17.3	96.4 (16.0)	97.9 (17.7)	100.05 (16.9)	101.8 (17.8)	122.3 (19.7)	125.2 (21.8)

Tread = treadmill

Table 3-10: Heart rate in beats per minute (HR, bpm) at 40%, 80%, and 100% of VO_{2peak}

HR, bpm	40% VO_{2peak} M (SD)		80% VO_{2peak} M (SD)		100% VO_{2peak} M (SD)	
	Cycle	Treadmill	Cycle	Treadmill	Cycle	Treadmill
Male	91.6 (19.5)	93.3 (18.4)	106.5 (23.0)	111.2 (23.5)	119.3 (23.6)	123.3 (26.4)
Female	86.3 (10.4)	90.7 (10.7)	109.1 (7.9)	114.4 (12.9)	128.6 (11.4)	129.4 (14.7)
Total	89.6 (16.6)	92.4 (15.7)	107.5 (18.6)	112.4 (19.9)	122.7 (20.1)	125.5 (22.5)

Minute ventilation (V_E)

A significant main effect for work stage was seen for V_E values at both absolute work stages (F(4,15)=48.422, $p<0.01$, $\eta^2=0.928$) and at relative work stages (F(2,16)=71.546, $p<0.01$, $\eta^2=0.899$). However, there were no significant differences observed between modalities and sexes.

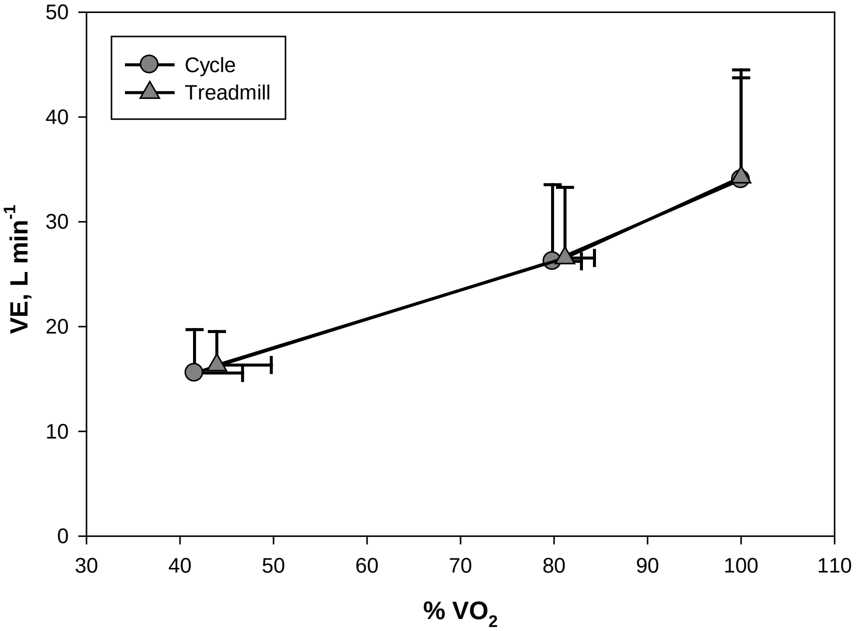

Figure 3-5: Changes in minute ventilation (V_E) relative to oxygen uptake (% VO_{2peak}) during cycle and treadmill CPET. Data are presented for 40%, 80%, and 100% of VO_{2peak}.

Tidal volume (V_T)

When analyzing the values at the absolute work stages, there was a significant main effect for work stage (F(4,15)=30.553, $p<0.01$, $\eta^2=0.891$) and modality (F(1,18)=12.903, $p<0.01$, $\eta^2=0.418$), where tidal volume was significantly greater on the treadmill than on the cycle ergometer. At the relative workstages, the main effect for modality became borderline significant (F(1,17)=4.302, p=0.054, $\eta^2=0.202$). Women showed a greater difference in V_T between treadmill and cycle exercise, however, this interaction was not significant (F(1,18)=3.312, p=0.085, $\eta^2=0.155$).

Table 3-11: Tidal volume in L min^{-1} (V_T) at baseline, work stages 1, 2, and 3, and peak exercise.

V_T, L min^{-1}	Baseline M (SD)		Work stage 1 M (SD)		Work stage 2 M (SD)		Work stage 3 M (SD)		Peak M (SD)	
	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread
Male	0.867 (0.152)	0.868 (0.130)	1.044 (0.130)	1.079 (0.186)	1.166 (0.209)	1.213 (0.193)	1.207 (0.232)	1.230 (0.188)	1.559 (0.540)	1.602 (0.536)
Female	0.603 (0.129)	0.692 (0.122)	0.776 (0.110)	0.859 (0.172)	0.886 (0.114)	0.991 (0.202)	0.935 (0.118)	1.022 (0.166)	1.227 (0.361)	1.314 (0.384)
Total	0.761 (0.193)	0.798 (0.152)	0.937 (0.180)	0.991 (0.208)	1.054 (0.224)	1.124 (0.221)	1.098 (0.235)	1.147 (0.204)	1.426 (0.495)	1.487 (0.491)

Tread = treadmill

Table 3-12: Tidal volume in L min^{-1} (V_T) at 40%, 80%, and 100% VO_{2peak}.

V_T, L min^{-1}	40% VO_{2peak} M (SD)		80% VO_{2peak} M (SD)		100% VO_{2peak} M (SD)	
	Cycle	Treadmill	Cycle	Treadmill	Cycle	Treadmill
Male	1.009 (0.156)	1.030 (0.253)	1.491 (0.460)	1.518 (0.526)	1.559 (0.540)	1.603 (0.535)
Female	0.773 (0.160)	0.888 (0.213)	1.142 (0.279)	1.259 (0.400)	1.266 (0.372)	1.335 (0.409)
Total	0.922 (0.193)	0.978 (0.243)	1.363 (0.431)	1.422 (0.489)	1.451 (0.496)	1.505 (0.499)

Respiratory rate (RR)

A significant main effect for work stage ($F(4,15)=20.683$, $p<0.01$, $\eta^2=0.847$ (absolute) and $F(2,16)=46.678$, $p<0.01$, $\eta^2=0.854$ (relative)) was observed for respiratory rate. There was no significant effect for either modality or sex.

Table 3-13: Respiratory rate in breaths per minute (RR, bpm) at baseline, work stages 1, 2, and 3, and peak exercise.

RR, bpm	Baseline M (SD)		Work stage 1 M (SD)		Work stage 2 M (SD)		Work stage 3 M (SD)		Peak M (SD)	
	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread
Male	20.4 (5.4)	20.3 (6.2)	23.2 (5.1)	23.5 (6.6)	24.0 (5.1)	23.8 (6.8)	25.8 (5.9)	25.3 (6.2)	32.2 (7.6)	30.7 (6.1)
Female	23.6 (5.2)	21.6 (4.0)	25.8 (3.0)	25.5 (6.5)	26.3 (3.0)	26.8 (7.3)	28.4 (4.7)	26.9 (6.6)	37.1 (8.6)	36.4 (7.9)
Total	21.7 (5.4)	20.8 (5.3)	24.2 (4.5)	24.3 (6.5)	24.9 (4.4)	25.0 (7.0)	26.8 (5.5)	26.0 (6.2)	34.2 (8.2)	33.1 (7.2)

Tread = treadmill

Table 3-14: Respiratory rate in breaths per minute (RR, bpm) at 40%, 80%, and 100% of VO_{2peak}.

RR, bpm	40% VO_{2peak} M (SD)		80% VO_{2peak} M (SD)		100% VO_{2peak} M (SD)	
	Cycle	Treadmill	Cycle	Treadmill	Cycle	Treadmill
Male	22.9 (5.3)	22.9 (5.8)	26.0 (5.4)	25.8 (6.3)	32.2 (7.6)	30.6 (6.0
Female	26.6 (2.5)	26.3 (6.5)	31.7 (4.7)	30.1 (6.3)	38.7 (7.9)	38.0 (6.9)
Total	24.3 (4.8)	24.2 (6.1)	28.1 (5.8)	27.4 (6.5)	34.6 (8.2)	33.3 (7.2)

Oxygen saturation (SpO_2)

Analysis performed for SpO_2 values both at absolute and relative work stages showed a significant main effect for work stage ($F(4,15)=6.758$, $p<0.01$, $\eta^2=0.643$ and $F(2,16)=7.016$, $p<0.01$, $\eta^2=0.467$ respectively) and for modality ($F(1,18)=8.478$, $p<0.01$, $\eta^2=0.320$ and $F(1,17)=9.286$, $p<0.01$, $\eta^2=0.353$), where SpO_2 values were lower with treadmill walking throughout all work stages. A significant interaction was observed between work stage and modality $F(4,15)=3.553$, $p<0.01$, $\eta^2=0.487$), and whereas there was no difference between treadmill and cycle exercise at baseline and the first work stage, there was a difference between modalities at the higher work stages and peak exercise. However, when comparing the relative work stages the significant interaction between work stage and modality disappears. There were no observed between-sex differences.

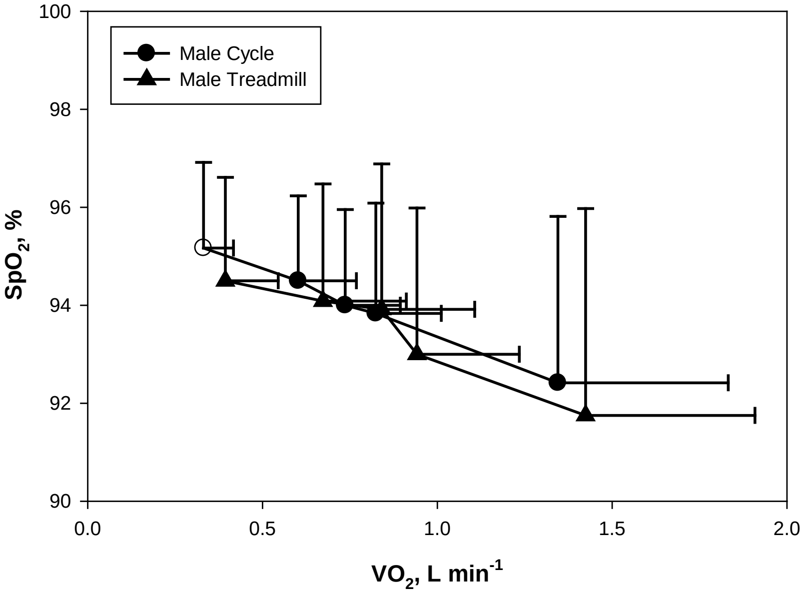

Figure 3-6: Changes in oxygen saturation ($SpO_{2,}$ %) relative to oxygen uptake (VO2, L min^{-1}) during cycle and treadmill CPET in men. Data are presented for baseline (0 watts), the initial three stages of the CPET and at peak exercise.

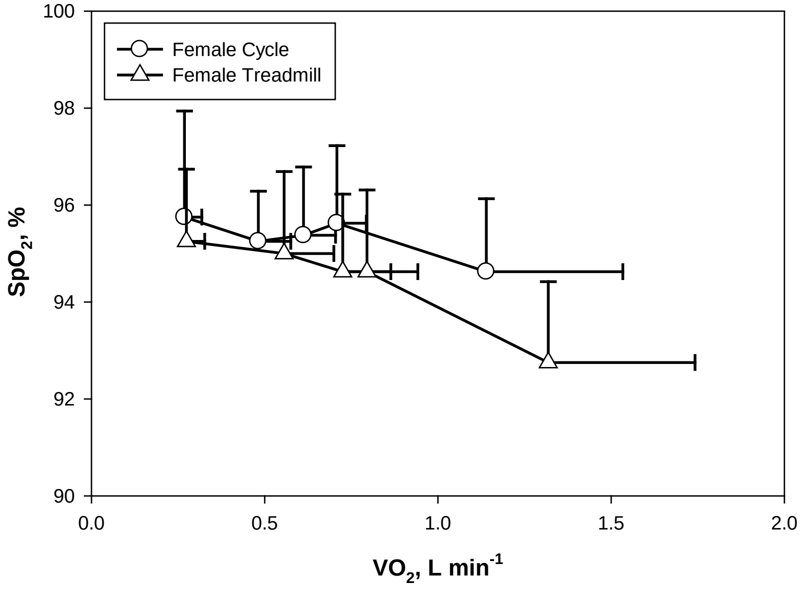

Figure 3-7: Changes in oxygen saturation ($SpO_{2,}$ %) relative to oxygen uptake (VO2, L min^{-1}) during cycle and treadmill CPET in men. Data are presented for baseline (0 watts), the initial three stages of the CPET and at peak exercise.

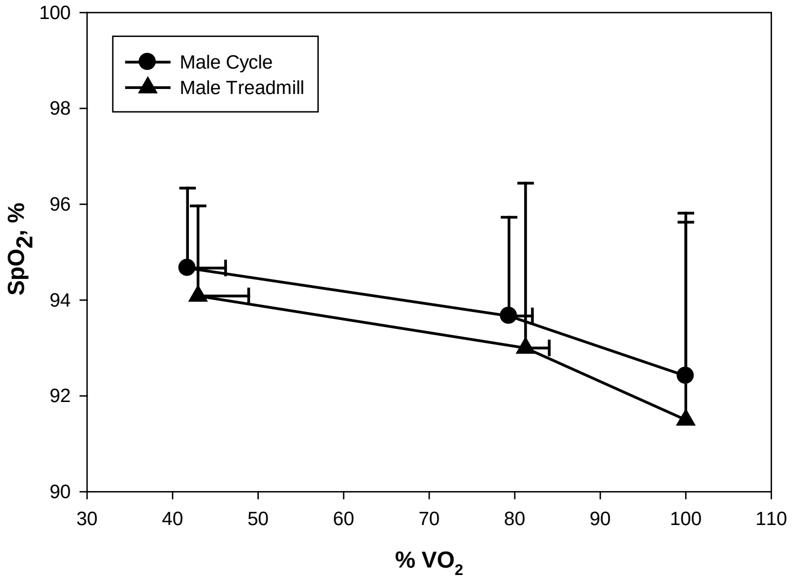

Figure 3-8: Changes in oxygen saturation (SpO_2, %) relative to oxygen uptake (VO_{2peak}) during cycle and treadmill CPET in men. Data are presented for 40%, 80%, and 100% of VO_{2peak}.

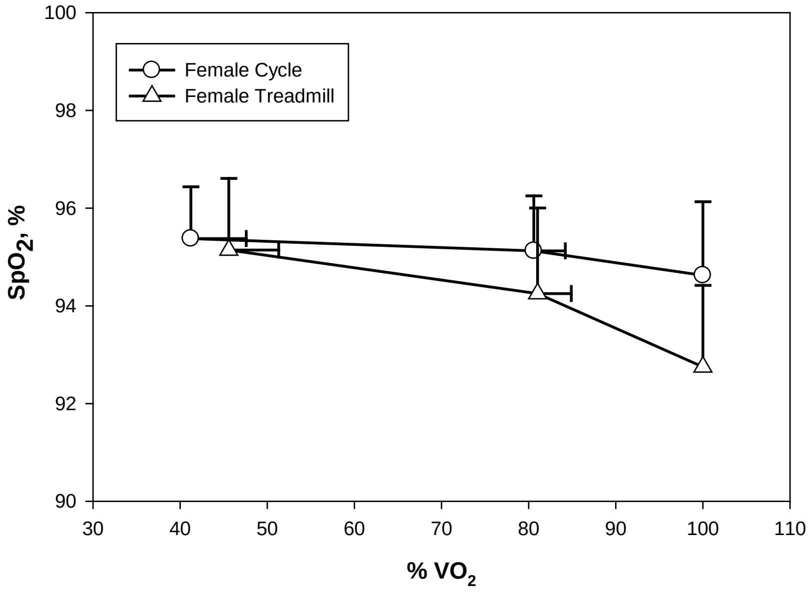

Figure 3-9: Changes in oxygen saturation (SpO_2, %) relative to oxygen uptake (VO_{2peak}) during cycle and treadmill CPET in women. Data are presented for 40%, 80%, and 100% of VO_{2peak}.

Ventilatory slope for oxygen (V_E/VO_2)

A significant main effect for work stage at absolute (F(4,15)=22.497, $p<0.01$, $\eta^2=0.857$) and relative work stages (F(2,16)=26.819, $p<0.01$, $\eta^2=0.770$), and modality at absolute (F(1,18)=13.594, $p<0.01$, $\eta^2=0.430$) and relative work stages (F(1,17)=18.415, $p<0.01$, $\eta^2=0.520$) were observed for the ventilatory slope for VO_2. The slope was greater for cycling than for treadmill walking throughout the test. There was no main effect or interactions involving between-sex differences.

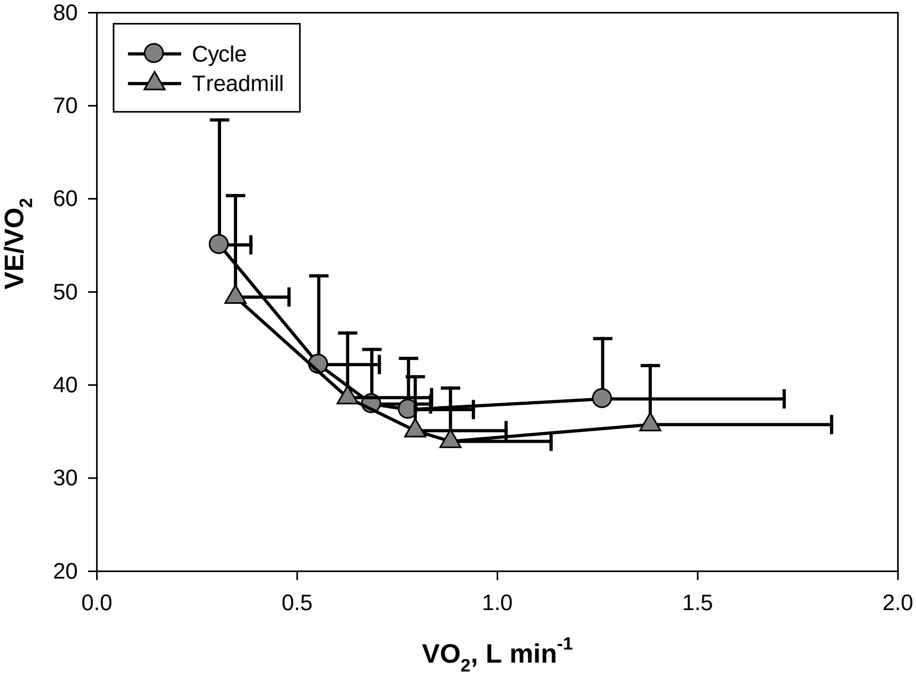

Figure 3-10: Changes in ventilatory slope for oxygen uptake (V_E/VO_2) relative to oxygen uptake (VO_2, L min^{-1}) during cycle and treadmill CPET. Data are presented for baseline (0 watts), the three initial stages of the CPET and at peak exercise.

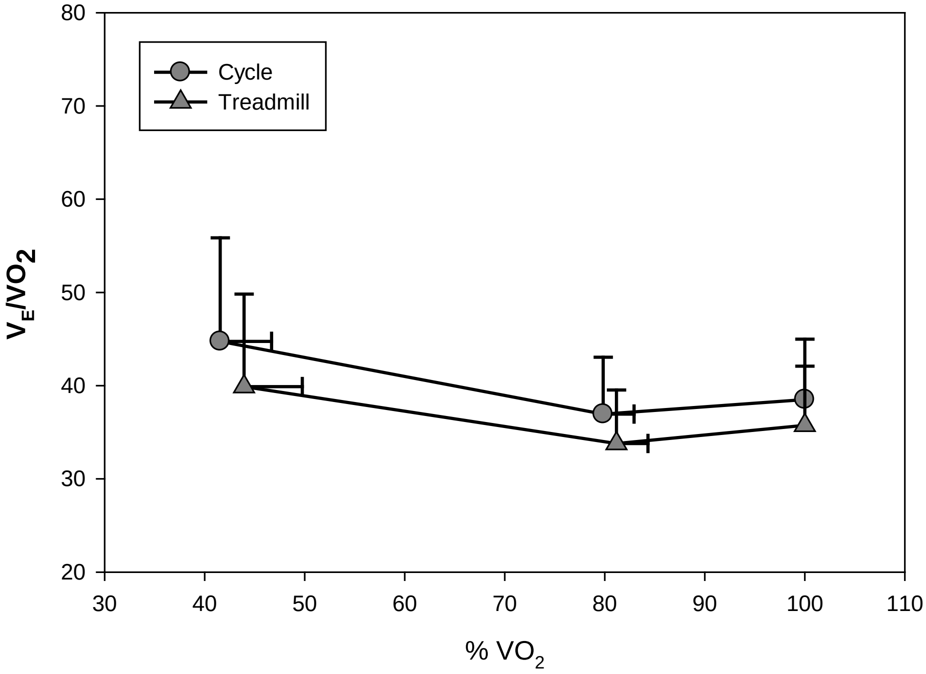

Figure 3-11: Changes in ventilatory slope for oxygen uptake (V_E/VO_2) relative to oxygen uptake (% VO_{2peak}) during cycle and treadmill CPET. Data are presented for 40%, 80%, and 100% of $VO_{2peak.}$

Ventilatory slopes for carbon dioxide (V_E/VCO_2)

A significant main effect for work stage was observed for the ventilator slope for VCO_2 (F(4,15)=35.116, p<0.01, η^2=0.904 (absolute) and F(2,16)=55.056, p<0.01, η^2=0.873 (relative), whereas no significant effect were observed for either modality or sex.

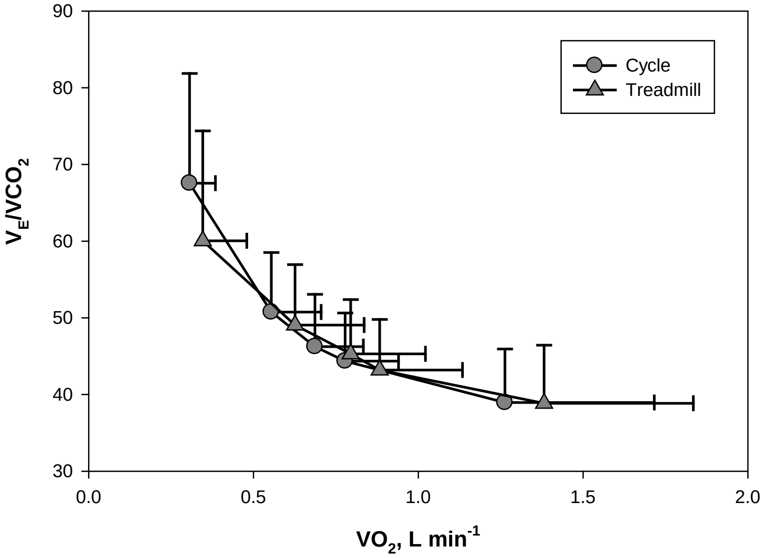

Figure 3-12: Changes in ventilatory slope for carbon dioxide production (V_E/VCO_2) relative to oxygen uptake (VO_2, L min^{-1}) during cycle and treadmill CPET. Data are presented for baseline (0 watts), the three initial stages of the CPET and at peak exercise.

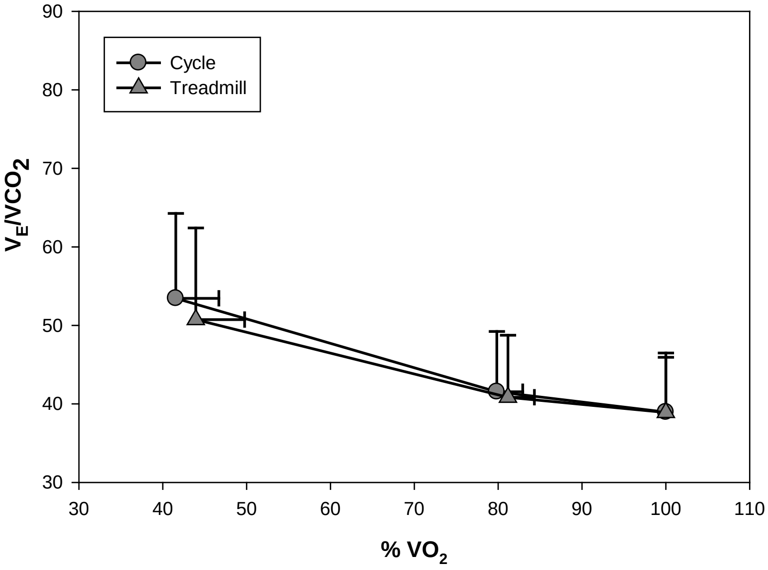

Figure 3-13: Changes in ventilatory slope for carbon dioxide production (V_E/VCO_2) relative to oxygen uptake (% VO_{2peak}) during cycle and treadmill CPET. Data are presented for 40%, 80%, and 100% of $VO_{2peak.}$

Respiratory exchange ratio (RER)

A significant main effect for absolute (F(4,15)=27.759, $p<0.01$, $\eta^2=0.881$) and relative (F(2,16)=41.546, $p<0.01$, $\eta^2=0.839$) work stages were observed. A significant main effect for modality (F(1,18)=15.685, $p<0.01$, $\eta^2=0.466$ (absolute) and F(1,17)=23.672, $p<0.01$, $\eta^2=0.582$(relative)) was observed, with greater RER values on the cycle test than the treadmill test throughout the test. There was a significant interaction between work stage and modality (F(4,15)=7.365, $p<0.01$, $\eta^2=0.663$), where differences in RER appeared to increase between modalities at advancing work stages with the cycle RER having a steeper slope than the treadmill RER. A significant interaction was observed between work stage and sex at the relative work stages (F(2,16)=5.645, $p<0.05$ ($p=0.014$), $\eta^2=0.414$), where women had a greater increase in RER from 80% of VO_{2peak} to peak exercise compared to men. This difference was, however, not significant at the absolute work stages.

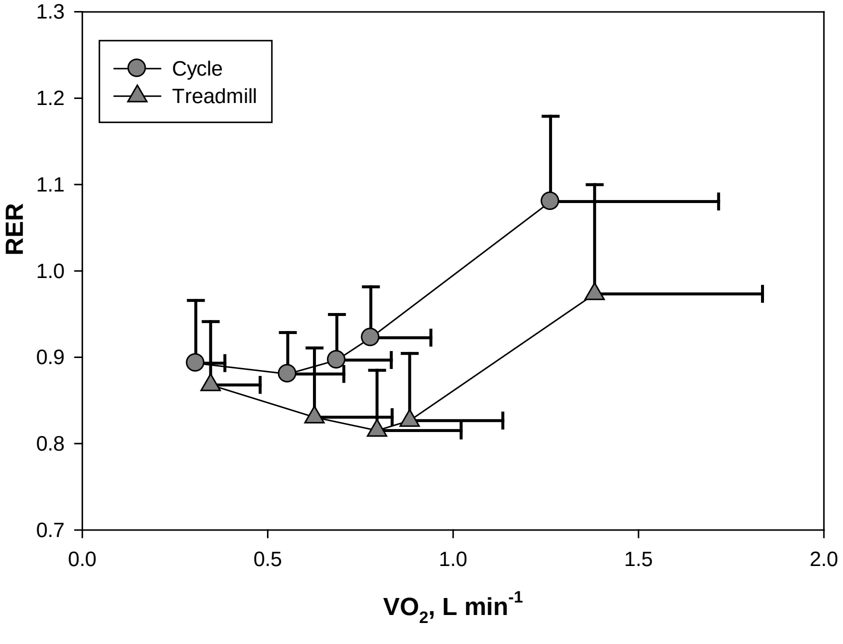

Figure 3-14: Changes in respiratory exchange ratio (RER) relative to oxygen uptake (VO_2, L min^{-1}) during cycle and treadmill CPET. Data are presented at baseline (0 watts), the initial three stages of the CPET and at peak exercise.

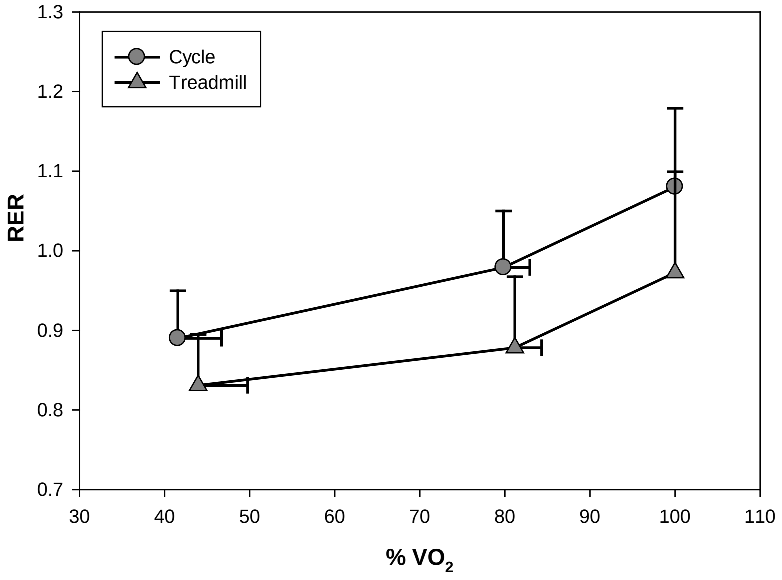

Figure 3-15: Changes in respiratory exchange ratio (RER) relative to oxygen uptake (%VO_{2peak}) during cycle and treadmill CPET. Data are presented at 40%, 80%, and 100% of VO_{2peak}.

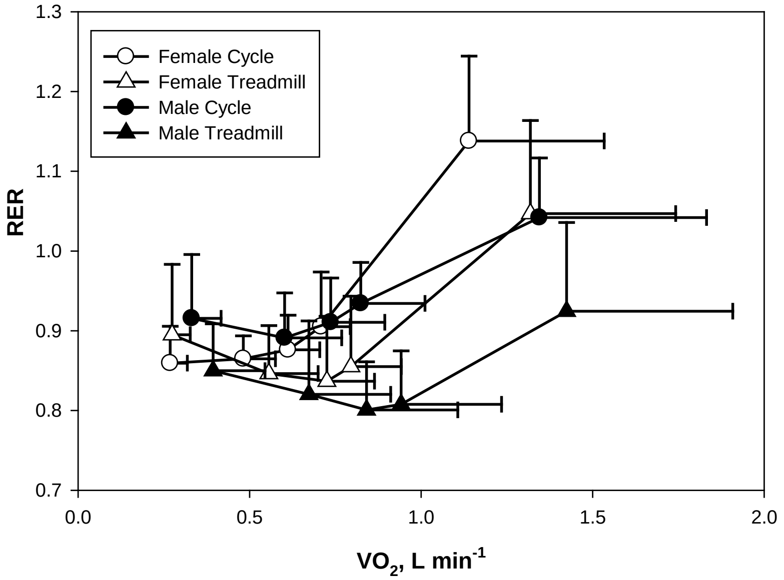

Figure 3-16: Changes in respiratory exchange ratio (RER) relative to oxygen uptake (VO_2, L min^{-1}) during cycle and treadmill CPET in men and women. Data are presented at baseline (0 watts), the initial three stages of the CPET and at peak exercise.

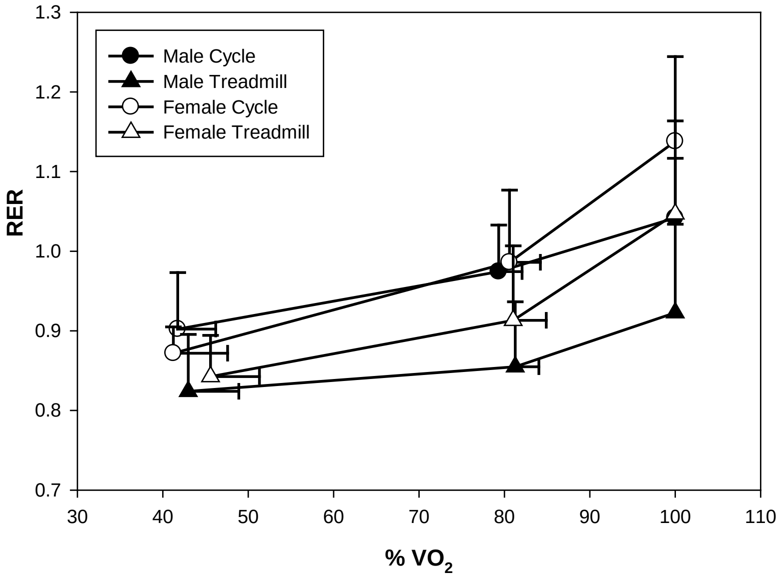

Figure 3-17: Changes in respiratory exchange ratio (RER) relative to oxygen uptake (%VO_{2peak}) during cycle and treadmill CPET in men and women. Data are presented at 40%, 80%, and 100% of $VO_{2peak.}$

Inspiratory capacity (IC)

IC maneuvers were performed at baseline, every two minutes, and at peak exercise. In order to keep all the subjects in the analysis, only three work stages were analyzed (baseline, 2 min, and peak). The IC maneuvers were not analyzed in terms of relative work stages for this same reason, that a high percentage of participants were lost in the analysis. A significant main effect for work stage was observed (F(2,17)=38.609, $p<0.01$, $\eta^2=0.820$), where the IC (L) decreased with increasing exercise. There was no difference between IC performed on the treadmill and the cycle, but a significant interaction was observed for work stage and sex (F(2,17)=7.197, $p<0.01$, $\eta^2=0.458$), with men having a greater decrease in IC from baseline to peak exercise than the women.

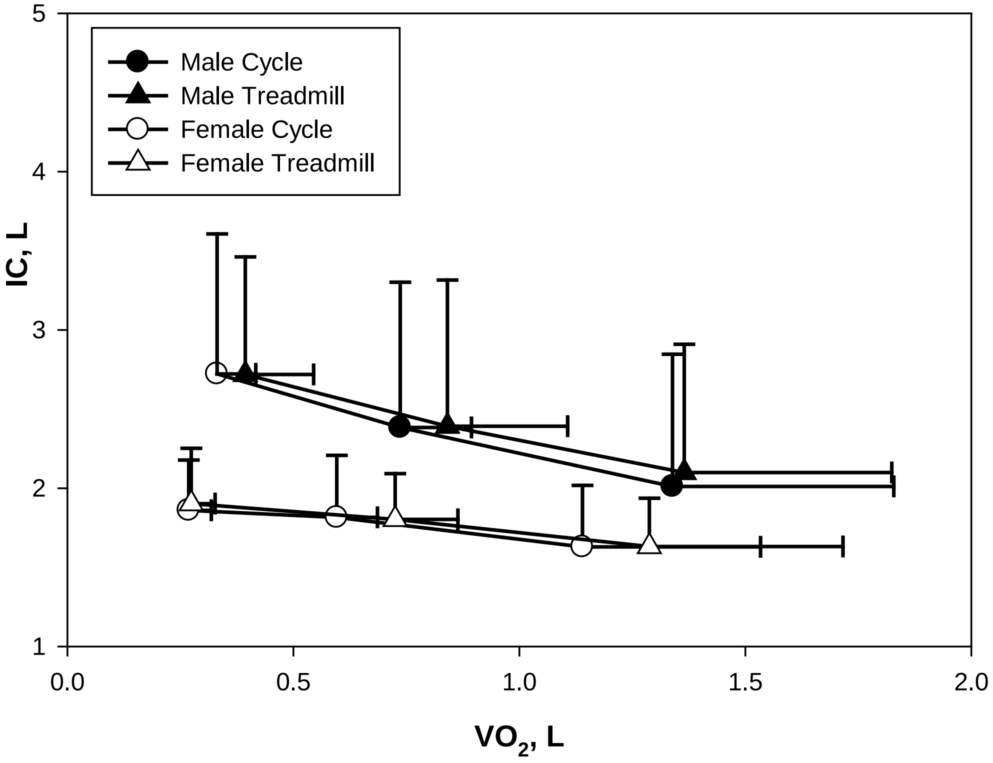

Figure 3-18: Changes in inspiratory capacity (IC, L min^{-1}) in relation to oxygen uptake (VO_2, L min^{-1}) during cycle and treadmill CPET in men and women. Data are presented for baseline (0 watts), the three initial stages of the CPET and at peak exercise.

Breathing discomfort

There was a significant main effect for both absolute (F(3,16)=43.713, $p<0.01$, $\eta^2=0.891$) and relative (F(2,14)=54.412, $p<0.01$, $\eta^2=0.886$) work stages. However, there was no significant difference for either modalities or sexes.

Table 3-15: Breathing discomfort (0-10) at baseline, time point 1 and 2, and peak exercise

Breathing discomfort	Baseline M (SD)		BFS 1 M (SD)		BFS 2 M (SD)		Peak M (SD)	
	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread
Male	0.6 (1.0)	0.5 (1.0)	0.9 (1.4)	0.6 (1.2)	1.5 (1.9)	1.6 (1.8)	4.6 (1.8)	4.5 (2.6)
Female	0.0 (0.0)	0.1 (0.2)	0.0 (0.0)	0.1 (0.2)	0.1 (0.2)	0.6 (0.7)	3.0 (1.5)	2.8 (1.0)
Total	0.35 (0.8)	0.3 (0.8)	0.6 (1.1)	0.4 (0.9)	0.9 (1.6)	1.2 (1.6)	4.0 (1.8)	3.8 (2.2)

Tread = treadmill

Table 3-16: Breathing discomfort (0-10) at 40%, 80%, and 100% of VO_{2peak}

Breathing discomfort	40% VO_{2peak} M (SD)		80% VO_{2peak} M (SD)		100% VO_{2peak} M (SD)	
	Cycle	Treadmill	Cycle	Treadmill	Cycle	Treadmill
Male	0.6 (1.0)	0.6 (1.0)	1.9 (1.7	2.1 (1.9)	4.4 (1.7)	4.6 (2.7)
Female	0.0 (0.0)	0.2 (0.4)	1.7 (1.2)	1.0 (.9)	3.3 (1.0)	2.8 (1.2
Total	0.4 (0.9)	0.4 (0.9)	1.8 (1.5)	1.7 (1.7)	4.0 (1.5)	4.0 (2.4)

Leg discomfort

There was a significant main effect for work stage, both for absolute work stages (F(3,16)=47.598, p<0.01, η^2=0.899) and relative work stages (F(2,14)=49.239, p<0.01, η^2=0.876). A significant interaction was observed between work stage and modality at absolute work stages (F(3,16)=3.458, p<0.05, η^2=0.393), where cycling generated greater leg discomfort than walking with advancing exercise. A significant interaction was also observed between modality and sex (F(1,15)=5.222, p<0.05, η^2=0.258), where men reported similar leg discomfort with both cycling and walking, whereas women reported greater leg discomfort with cycling as compared to walking. Additionally a significant interaction was observed for work stage, modality, and sex at relative work stages (F(2.14)=3.959, p<0.05, η^2=0.361), with a borderline significance at absolute work stages (F(3,16)=3.053, p=0.059, η^2=0.364). Whereas the men had a linear increase in leg discomfort with both exercise modalities throughout the test, the women had less of an increase in leg discomfort at the early stages of the exercise test, with a steeper increase in leg discomfort towards peak exercise especially on the cycle ergometer.

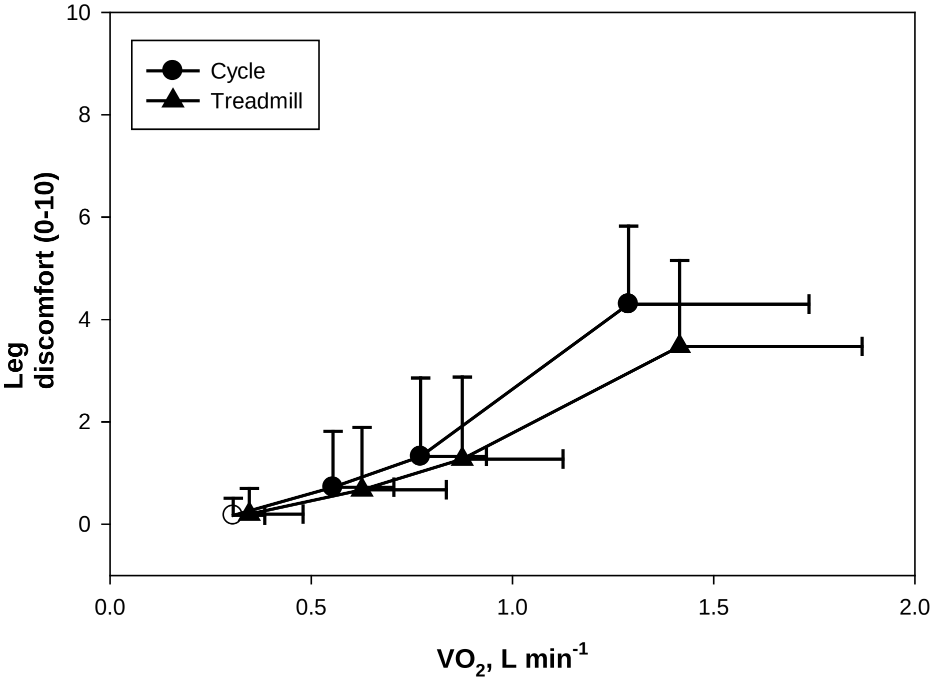

Figure 3-19: Changes in leg discomfort (0-10) in relation to oxygen uptake (VO$_2$, L min^{-1}) during cycle and treadmill CPET. Data are presented for baseline (0 watts), the initial two time points, and at peak exercise.

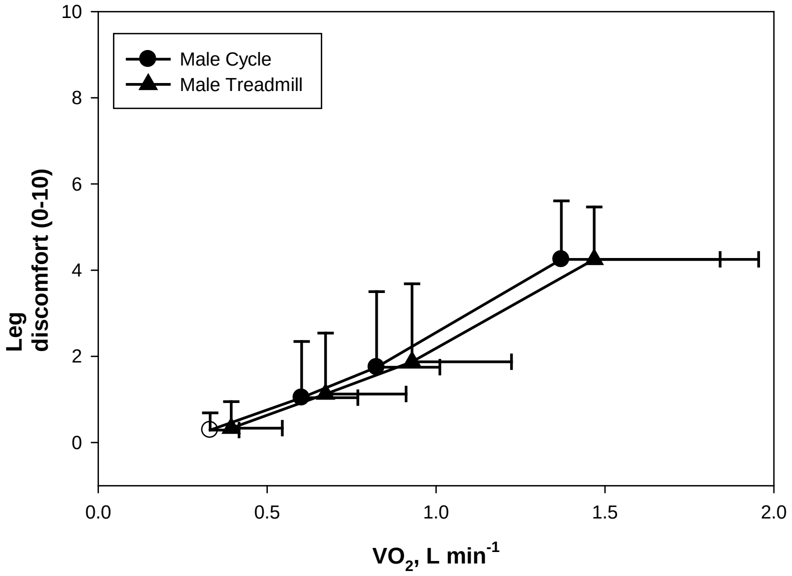

Figure 3-20: Changes in leg discomfort (0-10) in relation to oxygen uptake (VO$_2$, L min^{-1}) during cycle and treadmill CPET in men. Data are presented for baseline (0 watts), the initial IC time points, and at peak exercise.

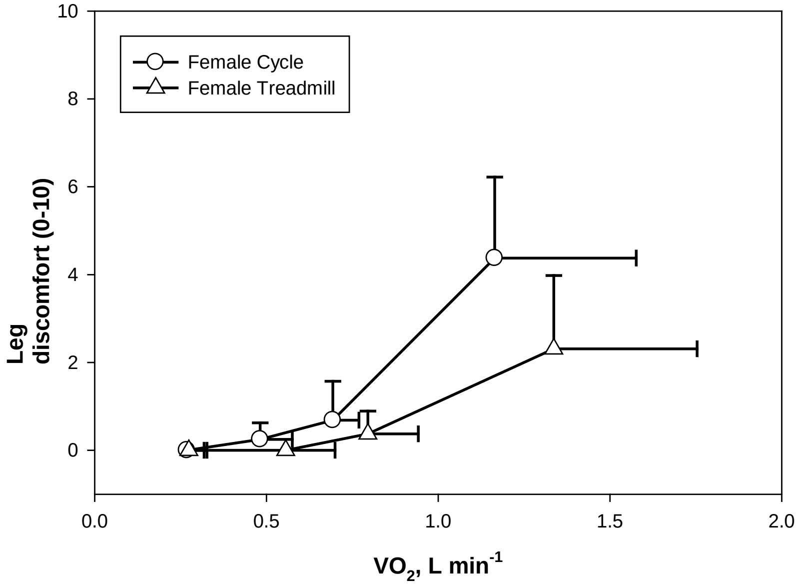

Figure 3-21: Changes in leg discomfort (0-10) in relation to oxygen uptake (VO$_2$, L min^{-1}) during cycle and treadmill CPET in women. Data are presented for baseline (0 watts), the initial IC time points, and at peak exercise.

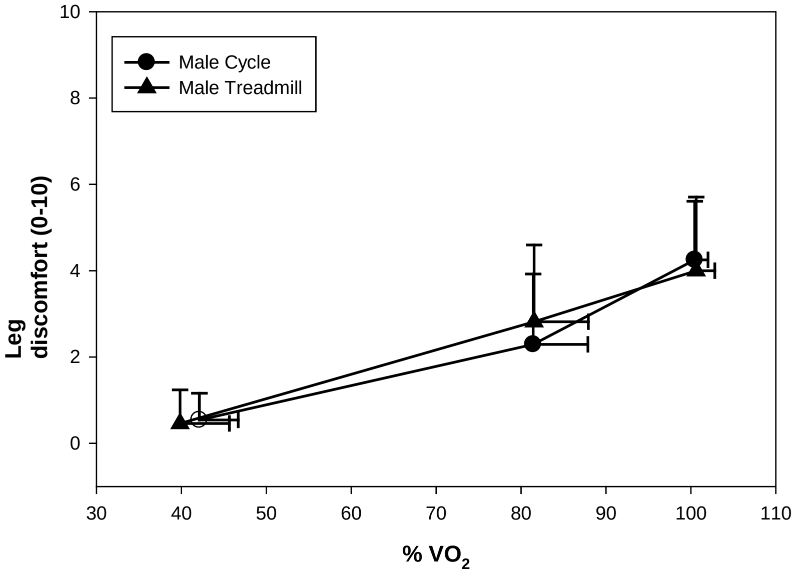

Figure 3-22: Changes in leg discomfort (0-10) in relation to oxygen uptake (%VO_{2peak}) during cycle and treadmill CPET in men. Data are presented for 40%, 80%, and 100% of VO_{2peak}.

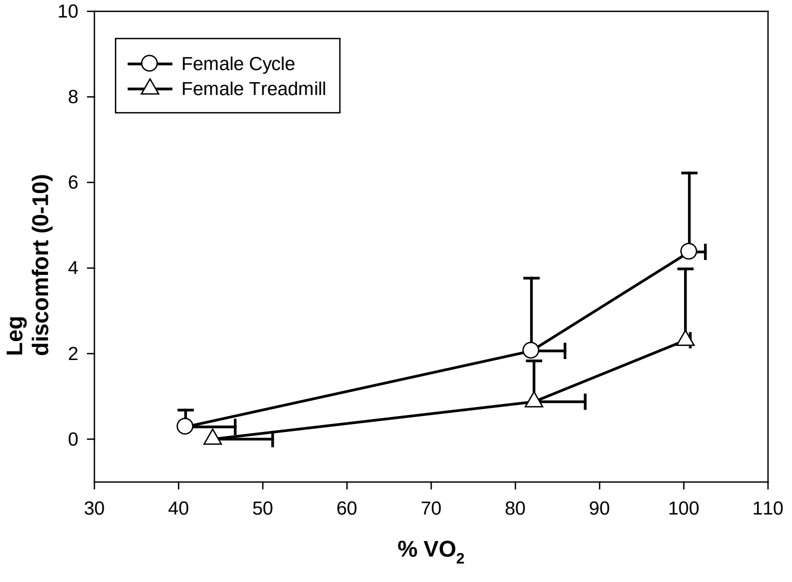

Figure 3-23: Changes in leg discomfort (0-10) in relation to oxygen uptake (%VO_{2peak}) during cycle and treadmill CPET in women. Data are presented for 40%, 80%, and 100% of VO_{2peak}.

Feeling state (FS)

A significant main effect for work stage was observed for reported scores on the Feeling Scale at absolute work stages (F(3,14)=21.471, $p<0.01$, $\eta^2=0.821$) as well as relative work stages (F(2,14)=37.179, $p<0.01$, $\eta^2=0.842$). At relative work stages, a significant main effect was also seen for modality (F(1,15)=5.472, $p<0.05$, $\eta^2=0.267$), with lower scores with treadmill walking compared to cycling. However, there was no significant main effect for modality at the absolute work stages. For both exercise modalities, the females reported higher scores than the males. However, this difference was not significant.

Table 3-17: Feeling state at baseline, time point 1 and 2, and peak exercise

FS	Baseline M (SD)		BFS 1 M (SD)		BFS 2 M (SD)		Peak M (SD)	
	Cycle	Tread	Cycle	Tread	Cycle	Tread	Cycle	Tread
Male	1.9 (1.6)	1.9 (2.0)	2.0 (1.5)	1.6 (1.8)	1.4 (2.0)	0.8 (2.1)	-0.3 (1.7)	-1.8 (1.9)
Female	3.3 (1.5)	2.3 (2.7)	3.0 (1.3)	2.8 (1.6)	2.7 (1.5)	2.8 (1.6)	0.5 (2.0)	-0.3 (2.7)
Total	2.4 (1.7)	2.1 (2.2)	2.3 (1.5)	2.0 (1.8)	1.8 (1.9)	1.5 (2.1)	0.0 (1.8)	-1.3 (2.2)

Tread = treadmill

Table 3-18: Feeling state at 40%, 80%, and 100% of VO_{2peak}

FS	40% VO_{2peak} M (SD)		80% VO_{2peak} M (SD)		100% VO_{2peak} M (SD)	
	Cycle	Treadmill	Cycle	Treadmill	Cycle	Treadmill
Male	2.1 (1.6)	1.8 (1.9)	1.6 (2.0)	0.5 (2.2)	-0.2 (1.8)	-2.0 (1.9)
Female	2.7 (1.5)	2.8 (1.6)	2.2 (1.3)	1.5 (1.8)	0.5 (2.05)	-0.3 (2.7)
Total	2.3 (1.5)	2.2 (1.8)	1.8 (1.8)	0.8 (02.)	0.1 (1.8)	-1.4 (2.3)

Self-Efficacy

Task SE.

There was a significant main effect for pre-post test for task SE (F(1,15)=13.439, $P<0.01$, $\eta^2=0.473$), where an increase in task SE score was observed after both the CPETs. There was no significant main effect for either test

1 – test 2, or sex. However, a significant three-way interaction was observed between test 1 - test 2, sex and whether the first test was a treadmill or a cycle test (F(1,15)=5.190, $P<0.05$, $\eta^2=0.257$). Women had a greater increase in task SE after the first test, whereas the men had a similar increase after both tests. The women seemed to hang on to the SE change after the first test, but the men had fallen back down to their initial task SE score. Therefore, as the pre task SE scores were similar before the tests, a similar increase was seen after both tests in men. Further, it made no difference for task SE in women whether the first test was a cycle- or a treadmill CPET, but the men seemed to have a greater increase in task SE if the first test was a cycle-CPET. However, the men started out with a higher task score before the treadmill test, and both men and women ended up with a higher SE score after the treadmill tests.

Table 3-19: Task SE for test 1 (pre and post)

Task SE Test 1	Pre 1			Post 1		
	(Tread 1) Treadmill	(Cycle 1) Cycle	All	(Tread 1) Treadmill	(Cycle 1) Cycle	All
Male	73.1 (21.0)	72.1 (14.7)	72.7 (18.2)	83.8 (18.0)	87.9 (12.0)	85.3 (15.6)
Female	86.6 (14.1)	71.7 (26.0	81.0 (19.1)	97.1 (5.9)	88.3 (11.7)	93.8 (8.9)
Total	78.7 (19.0)	71.9 (18.3)	76.2 (18.5)	89.4 (15.4)	88.1 (10.8)	88.9 (13.6)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-20: Task SE for test 2 (pre and post)

Task SE Test 2	Pre 2			Post 2		
	(Tread 1) Cycle	(Cycle 1) Treadmill	All	(Tread 1) Cycle	(Cycle 1) Treadmill	All
Male	91.0 (10.5)	59.2 (42.5)	79.4 (29.4)	90.0 (11.7)	75.8 (20.1)	84.8 (15.9)
Female	88.3 (12.7)	96.7 (3.3)	91.5 (10.7)	97.0 (4.1)	95.0 (7.3)	96.3 (5.1)
Total	89.9 (11.0)	75.2 (36.2)	84.5 (23.7)	92.9 (9.7)	84.0 (18.0)	89.6 (13.6)

Tread 1 = first test treadmill, C1 = first test cycle

Coping SE.

A significant main effect for pre-post test was observed for coping SE (F(1,15)=5.931, P<0.05, η^2=0.283), with an increase in SE scores at post test measurements. Also, there was a significant main effect for test one versus test two (F(1,15)=11.087, P<0.01, η^2=0.425), with a greater increase in SE with the first assessment. There were no observed differences for exercise modality or sex.

Table 3-21: Coping SE for test 1 (pre and post)

Coping SE Test 1	Pre 1			Post 1		
	(Tread 1) Treadmill	(Cycle 1) Cycle	All	(Tread 1) Treadmill	(Cycle 1) Cycle	All
Male	62.6 (26.1)	48.8 (37.2)	57.6 (29.5)	69.3 (10.8)	62.5 (42.3)	66.8 (24.9)
Female	70.5 (18.1)	63.9 (30.8)	68.0 (21.7)	85.5 (16.7)	81.1 (15.4)	**83.9** (15.2)
Total	65.9 (22.5)	55.2 (32.8)	62.0 (26.4)	76.1 (15.3)	70.5 (32.7)	74.0 (22.5)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-22: Coping SE for test 2 (pre and post)

Coping SE Test 2	Pre 2			Post 2		
	(Tread 1) Cycle	(Cycle 1) Treadmill	All	(Tread 1) Cycle	(Cycle 1) Treadmill	All
Male	82.4 (20.6)	60.0 (35.0)	74.2 (27.4)	81.9 (15.6)	66.7 (21.3)	76.4 (18.5)
Female	84.7 (7.3)	91.7 (4.4)	87.3 (7.0)	88.0 (10.7)	91.7 (4.4)	89.4 (8.6)
Total	83.3 (15.9)	73.6 (30.1)	79.7 (21.9)	84.4 (13.6)	77.4 (20.3)	81.8 (16.2)

Tread 1 = first test treadmill, C1 = first test cycle

Scheduling SE.

There was a significant main effect for pre-post test scheduling SE (F(1,15)=5.589, P<0.05, η^2=0.271). However, there were no significant differences between test 1 and test 2, and/or exercise modality. There was a significant effect for sex (F(1,15)=5.653, p<0.05, η^2=0.274), where women had greater scheduling SE at all time points.

Table 3-23: Scheduling SE for test 1 (pre and post)

Scheduling SE Test 1	Pre 1			Post 1		
	(Tread 1) Treadmill	(Cycle 1) Cycle	All	(Tread 1) Treadmill	(Cycle 1) Cycle	All
Male	72.1 (20.6)	58.8 (29.5)	67.3 (23.7)	75.2 (22.6)	65.4 (34.7)	71.7 (26.3)
Female	84.5 (19.2)	75.6 (36.7)	81.1 (24.8)	97.8 (4.4)	90.6 (13.6)	95.1 (8.8)
Total	77.3 (20.1)	66.0 (31.1)	73.1 (24.5)	84.6 (20.5)	76.2 (29.0)	81.5 (23.6)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-24: Scheduling SE for test 2 (pre and post)

Scheduling SE Test 2	Pre 2			Post 2		
	(Tread 1) Cycle	(Cycle 1) Treadmill	All	(Tread 1) Cycle	(Cycle 1) Treadmill	All
Male	85.7 (13.3)	59.2 (41.7)	76.1 (28.4)	81.0 (11.0)	65.4 (24.6)	75.3 (17.8)
Female	92.7 (8.3)	95.0 (1.7)	93.5 (6.5)	91.3 (10.4)	94.4 (1.9)	92.5 (8.1)
Total	88.6 (11.6)	74.5 (35.2)	83.4 (23.3)	85.3 (11.6)	77.9 (23.3)	82.5 (16.7)

Tread 1 = first test treadmill, C1 = first test cycle

State – Trait Anxiety Inventory (STAI): State anxiety

There were no significant main effects observed for the analysis of STAI trait anxiety scores before and after each of the exercise tests. However, an interaction effect was seen between pre-post scores and test one – test two scores ($F(1,15)=4.688$, $p<0.05$, $\eta^2=0.238$), where there was a reduction in STAI trait scores from pre to post measures after the first test while there was no difference, or rather a small increase in STAI trait scores from pre to post measures after the second test. An interaction effect was also seen between pre-post, test one – test two, and whether the first test was performed on the treadmill or cycle ($F(1,15)=6.549$, $p<0.05$, $\eta^2=0.304$). The STAI trait scores were reduced after the first exercise test on both the treadmill and cycle test. A further reduction in score was observed after the second test when this test was performed on a cycle, however, when the second test was performed on the treadmill, the STAI trait score increased after the test.

Table 3-25: STAI-state anxiety for test 1 (pre and post)

STAI-state Test 1	Pre 1			Post 1		
	(Tread 1) Treadmill	(Cycle 1) Cycle	All	(Tread 1) Treadmill	(Cycle 1) Cycle	All
Male	35.3 (4.1)	43.0 (3.8)	38.1 (5.4)	36.0 (6.4)	38.8 (5.6)	37.0 (6.0)
Female	36.2 (15.0)	32.0 (12.2)	34.6 (13.3)	32.0 (11.4)	27.7 (3.8)	30.4 (9.1)
Total	35.7 (9.6)	38.3 (9.6)	36.6 (9.4)	34.3 (8.6)	34.0 (7.4)	34.2 (8.0)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-26: STAI-state anxiety for test 2 (pre and post)

STAI-state Test 2	Pre 2			Post 2		
	(Tread 1) Cycle	(Cycle 1) Treadmill	All	(Tread 1) Cycle	(Cycle 1) Treadmill	All
Male	33.7 (9.3)	37.3 (11.5)	35.0 (9.8)	31.7 (9.4)	40.5 (11.2)	34.9 (10.5)
Female	32.0 (11.3)	27.3 (10.1)	30.3 (10.4)	29.0 (9.3)	33.7 (18.0)	30.8 (12.2)
Total	33.0 (9.7)	33.0 (11.3)	33.0 (10.0)	30.6 (9.0)	37.6 (13.5)	33.2 (11.1)

Tread 1 = first test treadmill, C1 = first test cycle

The Activation-Deactivation Adjective Check List

There was a significant main effect for factor (F(3,13)=6.550, p<0.01, η^2= 0.602), which was the only significant effect overall. A significant main effect for factor would be expected as the factors “measure different things”. There was no effect for pre-post scores, test 1versus test 2, exercise modality, and/or sex. The power of the analysis was very small as a result of the small sample size and the inclusion of the four factors (i.e. energetic, calmness, tired, and tension).

Table 3-27: Energetic arousal for test 1 (pre and post)

Energetic Test 1	Pre 1			Post 1		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	10.3 (2.6)	12.2 (5.3)	11.1 (3.8)	12.1 (3.4)	14.8 (3.1)	13.3 (3.4)
Test 1 C Test 2 T	12.0 (3.8)	12.3 (5.9)	12.1 (4.3)	13.8 (3.8)	14.0 (4.6)	13.9 (3.8)
Total	10.9 (3.0)	12.3 (5.1)	11.5 (3.9)	12.7 (3.5)	14.5 (3.4)	13.5 (3.5)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-28: Energetic arousal for test 2 (pre and post)

Energetic Test 2	Pre 2			Post 2		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	11.0 (4.1)	13.0 (5.5)	11.8 (4.6)	12.7 (4.2)	12.0 (6.0)	12.4 (4.8)
Test 1 C Test 2 T	10.8 (2.9)	13.7 (2.1)	12.0 (2.8)	10.0 (4.1)	12.0 (7.5)	10.9 (5.3)
Total	10.9 (3.5)	13.3 (4.3)	11.9 (3.9)	11.7 (4.2)	12.0 (6.1)	11.8 (4.9)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-29: Calmness arousal for test 1 (pre and post)

Calmness Test 1	Pre 1			Post 1		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	13.3 (2.1)	12.4 (3.6)	12.9 (2.7)	12.0 (2.2)	11.4 (3.0)	11.8 (2.5)
Test 1 C Test 2 T	12.5 (3.4)	12.0 (1.0)	12.3 (2.5)	14.3 (3.4)	11.3 (1.5)	13.0 (3.0)
Total	13.0 (2.5)	12.3 (2.8)	12.7 (2.6)	12.8 (2.8)	11.4 (2.4)	12.2 (2.7)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-30: Calmness arousal for test 2 (pre and post)

Calmness Test 2	Pre 2			Post 2		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	13.6 (3.0)	12.8 (2.4)	13.3 (2.7)	12.7 (3.6)	11.8 (2.4)	12.3 (3.1)
Test 1 C Test 2 T	11.3 (3.5)	11.3 (4.0)	11.3 (3.4)	12.8 (1.3)	10.7 (2.5)	11.9 (2.0)
Total	12.7 (3.3)	12.3 (2.9)	12.5 (3.0)	12.7 (2.9)	11.4 (2.3)	12.2 (2.7)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-31: Tired arousal for test 1 (pre and post)

Tired Test 1	Pre 1			Post 1		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	10.7 (3.4)	9.4 (4.8)	10.2 (3.9)	9.4 (2.0)	7.2 (2.9)	8.5 (2.6)
Test 1 C Test 2 T	10.0 (2.6)	10.7 (5.1)	10.3 (3.5)	10.3 (4.3)	10.0 (2.6)	10.1 (3.4)
Total	10.5 (3.0)	9.9 (4.6)	10.2 (3.6)	9.7 (2.8)	8.3 (3.0)	9.1 (2.9)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-32: Tired arousal for test 2 (pre and post)

Tired Test 2	Pre 2			Post 2		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	8.3 (5.0)	10.4 (6.3)	9.2 (5.4)	8.9 (2.5)	10.8 (6.3)	9.7 (4.3)
Test 1 C Test 2 T	10.5 (3.5)	11.3 (4.0)	10.9 (3.4)	10.0 (2.2)	11.3 (5.7)	10.6 (3.7)
Total	9.1 (4.5)	10.8 (5.3)	9.8 (4.7)	9.3 (2.3)	11.0 (5.6)	10.0 (4.0)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-33: Tension arousal for test 1 (pre and post)

Tension Test 1	Pre 1			Post 1		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	8.1 (3.3)	9.4 (5.2)	8.7 (4.0)	8.0 (3.5)	6.8 (2.7)	7.5 (3.1)
Test 1 C Test 2 T	10.0 (1.2)	9.7 (3.8)	9.9 (2.3)	8.5 (3.1)	6.3 (0.6)	7.6 (2.5)
Total	8.8 (2.8)	9.5 (4.4)	9.1 (3.5)	8.2 (3.2)	6.6 (2.1)	7.5 (2.8)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-34: Tension arousal for test 2 (pre and post)

Tension Test 2	Pre 2			Post 2		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	7.6 (2.7)	7.8 (4.1)	7.7 (3.2)	7.0 (2.5)	6.6 (2.2)	6.8 (2.3)
Test 1 C Test 2 T	9.5 (5.3)	9.0 (4.4)	9.3 (4.5)	10.0 (3.6)	8.0 (4.4)	9.1 (3.7)
Total	8.3 (3.7)	8.3 (3.9)	8.3 (3.7)	8.1 (3.1)	7.1 (2.9)	7.7 (3.0)

Tread 1 = first test treadmill, C1 = first test cycle

Feeling Scale

There were no significant effects for FS scores before and after each of the exercise tests, regardless of sex, test one – test two, pre – post, and/or whether test one was a treadmill or a cycle test.

Table 3-35: Feeling state for test 1 (pre and post)

Tension Test 1	Pre 1			Post 1		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	1.3 (1.3)	2.3 (2.2)	1.6 (1.6)	1.4 (1.5)	3.3 (2.4)	2.1 (2.0)
Test 1 C Test 2 T	1.5 (1.0)	1.3 (1.5)	1.4 (1.1)	1.0 (1.4)	2.3 (1.2)	1.6 (1.4)
Total	1.4 (1.1)	1.9 (1.9)	1.6 (1.4)	1.3 (1.4)	2.9 (1.9)	1.9 (1.7)

Tread 1 = first test treadmill, C1 = first test cycle

Table 3-36: Feeling state for test 2 (pre and post)

Tension Test 2	Pre 2			Post 2		
	Male	Female	All	Male	Female	All
Test 1 T Test 2 C	0.9 (1.2)	1.5 (1.0)	1.1 (1.1)	1.4 (1.6)	2.0 (1.2)	1.6 (1.4)
Test 1 C Test 2 T	0.5 (1.7)	2.3 (1.2)	1.3 (1.7)	0.5 (1.7)	2.0 (1.7)	1.1 (1.8)
Total	0.7 (1.3)	1.9 (1.1)	1.2 (1.3)	1.1 (1.6)	2.0 (1.3)	1.4 (1.5)

Tread 1 = first test treadmill, C1 = first test cycle

Chapter 4

DISCUSSION

This research study had three main focuses. The first purpose was to identify whether there was a difference in physiological responses to cardiopulmonary exercise testing on a treadmill and a cycle ergometer in patients with COPD. Secondly, the aim was to determine if the CPET influenced COPD patients' SE for exercise, and if the results were influenced by the exercise modality used (i.e., treadmill versus cycle ergometer) for the CPET. The third purpose of the study was to determine if the physiological and psychological responses to treadmill CPET and cycle CPET differed between men and women.

We demonstrated that an estimated linear increase in power output on the treadmill resulted in what appeared to be linear increases in physiological responses such as VO_2, HR, and V_E similar to those seen with cycle exercise, and there was no obvious advantage of using either the treadmill or the cycle ergometer. Further, the study showed that a CPET was beneficial for increasing the participants' task, coping, and scheduling SE for exercise, regardless of exercise modality and/or sex. Similarly, there were no major differences between men and women for treadmill CPET and cycle CPET.

Participants

All participants included in the study were referred to the Breathe Easy pulmonary rehabilitation program by a physician as they were symptomatic COPD patients. Thus, the mildest, asymptomatic COPD patients were likely missed in this study. Similarly, more debilitated patients with severe COPD (i.e., that were in need of long term oxygen therapy, had suffered resent exacerbations/hospitalizations, or that had orthopaedic limitations that would hinder treadmill CPET and/or cycle CPET) were also excluded from the study. Thus, the majority of the participants were categorized in Gold stage II and III according to their FEV_1 values, which limits the generalizability of the findings. Although the Breathe Easy program has an even ratio of women and men participating in the program, more men than women were included in this study.

Physiological responses to treadmill-CPET and cycle-CPET

Issues related to the CPET protocols.

A great advantage of the cycle-CPET is the precise quantification of external work and the linear increase in power output, which permits a steady rise in physiological responses and thus, a more precise estimation of VO_{2peak} (Wasserman et al., 2005). Estimation of linear power output on the treadmill has previously been attempted with different results. Porszasz et al (2003) proposed the use of an algorithm that included each individual's body weight to estimate linear increase in work rate on the treadmill for assessing subjects with severely limited exercise tolerance. This algorithm was recently used by Hsia et al (2009) when assessing 16 severe COPD patients and they found the physiological responses to the linear treadmill protocol to be similar to the cycle responses. Similarly to Hsia et al. (2009) we found that that the estimated linear treadmill protocol resulted in what appeared to be linear increase in metabolic responses such as VO_2, VCO_2, and HR.

As walking is a more familiar activity and engage larger muscle mass compared to cycling, greater VO_{2peak} values have been found with treadmill-CPET compared to cycle-CPET (Wasserman et al., 2005). Similar to previous research in COPD (Christensen, et al., 2004; Hsia, et al., 2009; Murray, et al., 2009), we also observed greater VO_{2peak} values with the treadmill-CPET compared to the cycle-CPET. In contrast to Hsia et al (2009), our participants achieved greater peak power output on the treadmill-CPET (80.8 (40.3) watts) compared to the cycle-CPET (70.3 (28.1) watts). Hsia et al (2009), found their participants achieved similar peak power output for both CPETs (71.9 (39.4) watts on the cycle and 70.1 (52.2) watts on the treadmill). The slopes of VO_2/power output appear to be slightly blunted on the treadmill-CPET in our participants, and a potential overestimation of peak power output on the treadmill-CPET in could potentially explain the difference between our findings and the findings of Hsia et al (2009). Previous research (Berling, Foster, Gibson, Doberstein, & Porcari, 2006) has shown that handrail holding on the treadmill decrease the metabolic rate for a given speed and grade, and may therefore influence the results and interpretation of the CPET. Handrail holding was continuously discouraged in our study, but as many of the participants had never been on a treadmill and COPD patients and older people in general may feel insecure on the treadmill, some patients were unable to comply with our request. We did not measure the amount of pressure the participants exerted on the handrails and this can therefore not be accounted for, but the participants may potentially have held on more tightly to the handrails as the treadmill incline became steeper toward peak exercise. Although the VO_2/power output slope may indicate a slight overestimation of peak power with treadmill-CPET, there was still a continuous increase in VO_2 toward peak exercise (Figure 3-1) and thus, VO_{2peak} may still have been representative.

Issues related to exercise duration.

Several researchers agree that the most informative CPETs bring the participants to exhaustion in 8 to 12 minutes (Ashley, et al., 2000; Buchfuhrer, et al., 1983; Myers, et al., 1991; Ross, et al., 2003; Wasserman, et al., 2005; Whaley, et al., 2006; Will & Walter, 1999). However, the majority of research did not utilize samples with CODP patients. Benzo et al. (2007) examined four different exercise protocols for use among COPD patients. They found that exercise duration of 5 to 9 minutes was more appropriate in COPD patients. However, further research needs to be done to support these findings.

Previous treadmill protocols with an estimated linear increase in work rate (i.e., Balke protocols) are often too short or too long, and terminated for reasons other than appropriate cardiovascular stress (Wasserman et al., 2005). The algorithm for the linear treadmill CPET used by Hsia et al (2009) was intended to bring the participants to exhaustion in ~10 minutes. In keeping with this, Hsia et al. (2009) found the treadmill-CPET to be terminated in 11.5 (2.8) minutes and the cycle-CPET to be terminated in 12.0 (2.1) minutes, both including 3 minutes of unloaded pedaling. Despite similar CPET protocols in our study and in the study by Hsia et al (2009) exercise duration was remarkably different, as our participants terminated the treadmill-CPET after 7.5 (2.9) minutes and the cycle-CPET after 6.7 (2.1) minutes.

The magnitude of change in power output for each increment was based on resting lung function (i.e. FEV_1) in both our study and in the study by Hsia et al. (2009). We increased the work rate with 5W min-1 for patients with $FEV_1 <$ 1L, and with 10W min-1 for patients with $FEV_1 >$ 1L. Hsia et al (2009) used the same FEV_1 values to determine work rate increments on the cycle-CPET. Hsia et al (2009), however, based their increments on the treadmill-CPET on peak power output achieved with the cycle-CPET. This can be both time consuming and unpractical in a clinical setting as it would require the performance of two CPETs. We, therefore, randomized the participants to start with either the treadmill-CPET or the cycle-CPET with similar increases in power output for both CPETs.

One possible explanation for the great variability found in the test durations among our COPD participants may be explained by the use of FEV_1 as the only determinant for magnitude of increase in power output. Changes in magnitude of increments were only done if the physician and technician thought a patient would exercise for more than 12 minutes with a 10W min-1 protocol, and work rate increments were then changed to 20W min-1. However, work rate increments were never adjusted down. Thus, if patients with FEV_1 >1L struggled with the 10W min-1 increments, the exercise test would still be completed with 10W min-1 increments, even though this could lead to short test durations. As a result of this, the patients with greater exercise capacity still completed the exercise test within the recommended duration of 12 minutes, whereas a few patients with decreased exercise capacity terminated the CPET in ~4 minutes. These participants with decreased exercise capacity could potentially have exercised for longer had the work rate increments been smaller. These findings speak to the importance of not solely using resting lung function (i.e. FEV_1) for determining the magnitude of the work rate increments. Perhaps an estimation of functional capacity including the MRC score in addition to FEV_1 values could be useful for evaluating the most appropriate work rate increments.

Another possible explanation for the differences found between our results and those of Hsia et al. (2009) may be differences in patient characteristics. Age, BMI, and smoking history were similar between the two study samples. However, our participants were diagnosed with less severe lung disease. Our participants had an average FEV_1 % predicted of 57.2 (19.1) compared to an average FEV_1% predicted of 36.5 (10.9) % in the study by Hsia et al (2009). As a result of this, more of the participants in the study by Hsia et al. (2009) were probably tested on the 5W min-1 protocol. As peak power output were similar in the two studies, this may explain the reason for why test durations in the study by Hsia et al. (2009) were longer, but it also may seem as if the participants in the study by Hsia et al. (2009) were more familiar with treadmill- and cycle exercise and had greater exercise capacity compared to our participants. Our participants had limited experience with both treadmill and cycle ergometer exercise, and only 1/3 of our participants had ever performed an exercise test before, and none had ever performed a cardiopulmonary exercise test. Furthermore, none of our patients were performing regular exercise before entering the PR program. Importantly, our sample is representative for the COPD patients entering the Breathe Easy program. Hsia et al (2009) does not report how and from where their participants were recruited, but it is likely that these patients were experienced with cardiopulmonary exercise testing. Thus, it is possible that the unfamiliarity of exercise testing in combination with lack of exercise experience would explain why our participants had similar peak power output to the patients in Hsia et al. (2009), despite having less severe lung disease.

Ventilatory responses to CPET.

It was predicted that an increased ventilatory response would be observed with the cycle-CPET compared to the treadmill-CPET. With cycle exercise, the metabolic cost of exercise is distributed over a smaller muscle mass. Consequently, as the metabolic demands of exercise increase, glycolysis is accelerated and an increase in lactate production and accumulation occurs. Excess non-metabolic CO_2 is produced as a result of bicarbonate buffering of the lactic acid (Milani, et al., 2006), and as the increased VCO_2 levels are detected by the chemoreceptors, ventilation is increased. Several researchers have demonstrated increased lactate levels with cycle-CPET compared to walking/treadmill-CPET (Christensen, et al., 2004; Mathur, et al., 1995; Palange, et al., 2000), and even though there were no measurements of lactate in this study, we also observed an increased ventilatory response with the cycle-CPET. Whereas the ventilatory slopes of V_E/VCO_2were similar for both exercise tests (Figure 3-12 and 3-13), the ventilatory slopes of V_E/VO_2 were greater with cycle-CPET (Figure 3-10 and 3-11). This was a result of similar V_{Epeak} and VCO_{2peak} values with both CPETs, whereas VO_{2peak} was significantly greater with the treadmill-CPET. Thus, although oxygen uptake was greater with the treadmill CPET the minute ventilation was similar. Additionally, RER (VCO_2/VO_2) values were significantly greater with the cycle-CPET (Figure 3-14). The accelerated response to ventilation on the cycle-CPET may have influenced the lower peak power output and VO_{2peak} with the cycle-CPET.

Inspiratory capacity (IC).

Despite the difference in ventilatory response with the two exercise modalities, all participants were ventilatory limited at peak exercise with both the treadmill – and the cycle-CPET. This finding was based on the measurements of IC from baseline throughout the exercise test. The ICs were used to detect changes in operating lung volumes. An upward shift in operating lung volumes is a typical finding in COPD patients (O'Donnell, D et al, 1994). This increase in end-expiratory lung volumes may initially be beneficial by increasing the generation of flow. However, the subject may become hyperinflated, experience increased work of breathing, become ventilatory limited and thus perceive greater dyspnea as the end-expiratory flow volume (EELV) approaches total lung capacity (TLC). As expected, a decrease in IC was observed from baseline to peak exercise. It appeared, however, to be no difference in the slope of decrease between CPETs on the treadmill and the cycle. Similar findings were reported by Hsia et al (2009). As there was no difference in the respiratory changes during the two exercise tests, the levels of breathing discomfort should also be similar between the two test modalities.

SpO_2.

Excessive oxygen desaturation is a common symptom in COPD and is therefore monitored closely during exercise. In the case of desaturation, additional oxygen therapy may be prescribed with physical activity. Previous studies have demonstrated a greater drop in oxygen saturation with treadmill-CPET compared to cycle-CPET (Christensen, et al., 2004; Hsia, et al., 2009; Man, et al., 2003; Murray, et al., 2009). Therefore, if a cycle-CPET underestimates oxygen desaturation, the appropriate therapy (i.e. oxygen therapy) may not be given to the patients who would benefit from this treatment. Similarly to the previous studies above, we also observed a greater drop in saturation with treadmill-CPET compared to cycle-CPET. The greater ventilatory response with the cycle-CPET could be the reason why SpO2 was better maintained on with the cycle-CPET, as an increase in minute ventilation compared to oxygen consumption may increase the alveolar and arterial oxygen content and thus oxygen saturation. However, we did not measure arterial oxygen content or arterial oxygen saturation invasively. We used a non-invasive pulse oximeter to estimate oxygen saturation (SpO_2). Previous research has demonstrated that pulse oximeters may be inaccurate during exercise due to poor signal because of motion (Plummer, Zakaria, Ilsley, Fronsko, & Owen, 1995) or gripping of the handlebars (Trivedi, Ghouri, Shah, Lai, & Barker, 1997). Our observed difference of 1.1% SpO2 between peak treadmill-CPET and cycle-CPET are within the standard error expected for oximeters (Powers et al., 1989; Yamaya, Bogaard, Wagner, Niizeki, & Hopkins, 2002), and an actual clinical difference can therefore not be noted. In order for oxygen desaturation to be properly evaluated, blood gases should be analyzed. If these analyzes are unavailable, the clinicians should be aware of the limitations of the oximeters and exert care when evaluating the results.

Breathing discomfort.

As predicted with increasing exercise, and a decrease in IC and shift in operational lung volumes, the level of breathing discomfort increased significantly from baseline to peak exercise. Similarly to the findings for IC, no significant difference in level of breathing discomfort was observed between the cycle-CPET and treadmill-CPET. There was also no overall difference in how people rated their reason for terminating the CPETs. These findings support the finding that the participants were ventilatory limited at peak exercise with both exercise modalities, and thus, both exercise modalities are equally useful for detecting ventilatory limitation in COPD patients.

Leg discomfort.

Increased lactate levels with cycling has previously been associated with earlier onset of leg discomfort in cycle exercise compared to walking (Mathur, et al., 1995; Palange, et al., 2000), however, both of these studies compared cycling to walking on level ground. As the participants in this study were walking up an incline, the leg muscles were activated differently than on level ground. Not surprisingly there was no difference in the level of leg discomfort between the CPET modalities at baseline and the early phases of exercise. However, as exercise progressed, there was a greater increase in leg discomfort with the cycle-CPET compared to the treadmill CPET, despite the great incline on the treadmill. Similar findings were presented by Hsia et al (2009). These findings may reflect the activation of smaller muscle mass, the level of lactate and VCO_2, and thus, greater muscle fatigue with the cycle-CPET compared to the treadmill-CPET.

Feeling state.

In general the participants felt worse with the treadmill-CPET compared to the cycle-CPET, despite an increased ventilatory response and greater leg discomfort with cycling. We found no obvious reason why the participants should feel worse on the treadmill. One plausible reason could be the importance of keeping up with the increasing speed and grade on the treadmill, and the fear of falling off the treadmill, however, this concept requires additional research. Perhaps having the patients specify more the reasons for why they feel a certain way during the CPET would give additional and interesting information in the future.

Overall physiological findings.

Our findings were, in general, similar to previously reported results comparing treadmill- and cycle-CPET (Christensen, et al., 2004; Hsia, et al., 2009; Murray, et al., 2009). Based on these findings we found no reasons for recommending one CPET-modality over another when testing patients with COPD. However, future studies on CPET in COPD should identify whether test durations should be shorter than CPET testing in healthy individuals or other patient groups. Furthermore, it is also important to test the usefulness of the linear treadmill protocol over a wide range of COPD disease severities in clinical practice, as well as to identify how appropriate power output increments should best be chosen.

Psychological responses to treadmill-CPET and cycle-CPET

Despite all the health benefits of exercise and PR, these benefits are often diminished or lost shortly after PR as a result of low adherence to post-program exercise regimens. Previous research have found SE to be associated with improvements in functional status and physical fitness (Bandura, 1997; Maddux, 1995; McAuly, 1994), and to be an important predictor of successful PR (Kaplan, Ries, Prewitt, & Eakin, 1994). Additionally, SE has been found to be an important predictor of long term exercise adherence in older adults (McAuley et al, 2003) and in patients with COPD (Bourbeau, et al., 2004). It is therefore, important to identify interventions that can increase SE, especially for exercise.

SE and CPET.

Patients may place great value on the performance and experience of the CPET, which takes place at their initial visit to the PR program. The initial visit may be associated with many new experiences such as a new location, new personnel, and new activities (exercise tasks). If circumstances are made ideal and the CPET is a positive experience, it could serve as a positive mastery experience and thus a positive source of SE. On the contrary, a negative experience could undermine SE. The CPET can therefore be important in the formation of efficacy expectations to the PR program (i.e., exercise). However, limited research has been performed on the effects of a CPET on SE in general, and no research that compared the effects of different CPETs on SE in patients with COPD was found. Ewart et al. (1983) demonstrated an increase in SE immediately after a treadmill-CPET, for activities similar to treadmill exercise (such as running, walking, and climbing) in patients after MI. In contrast, there was no increase in SE for activities dissimilar to treadmill exercise (i.e., arm activities and sexual intercourse) immediately after the test. However, once the participants had a positive feedback talk an increase in SE was seen also for activities dissimilar to walking on the treadmill (Ewart et al., 1983). In a study with mild to moderate heart failure patients, Oka et al (2005), however, reported no improvements in SE for walking, lifting, climbing, and general activity after a treadmill-CPET. Oka et al (2005) discussed whether disease severity and symptoms of dyspnea and fatigue could be reasons why they found a different change in SE from the acute bout of exercise compared to Ewart et al. (1983). Both the MI patients and the heart failure patients appear to be “healthier” in comparison to our COPD participants. We observed, similarly to Ewart et al. (1983), a significant increase in SE for exercise as a result of the CPET. Although some variability has been observed in the effects of a CPET on SE for exercise or exercise-related activities, all the studies show either an increase or no change in SE. Thus, the CPET does not seem to have a negative effect on SE. As detailed information from the two previous studies were limited, further comparisons between the three studies (i.e., measurement instruments, SE scores) were difficult to perform.

SE and exercise protocol.

Appropriate levels of challenge have been found to be important when encouraging people to adopt new activities, such as exercise (Ewart, 1989). As we observed no significant difference between increases in SE with the cycle-CPET and treadmill-CPET, it may be the CPET itself that helped create a positive mastery experience for our participants. One of the advantages with the exercise protocols chosen for this present study, were the implementation of low initial metabolic rate and a gradual increase in work with progressive exercise for most of the participants. This is an advantage for the physiological interpretation of the test, but it may also be advantageous for the patient’s feeling about the CPET. Rather than making the patients uncomfortable with e.g. treadmill speed that made them feel like they were falling off the treadmill and/or pedaling resistance that made them feel they could not move the pedals and/or experience muscle fatigue right from the start, the participants were eased into the exercise experience. This may potentially have influenced the perception of the test and hence the successful mastery experience and the patients might have finished the test with a feeling of “oh, that wasn’t so bad”. A larger sample it would be necessary to compare SE scores in patients who terminated the test early (~ 4 minutes) and in those who terminated the test later (within 8 – 10 minutes). The level of challenge might have been overwhelming in the participants who terminated the tests early.

Verbal persuasion has been found to be effective for enhancing a mastery experience, and Ewart et al. (1983) found SE changes for dissimilar activities to walking to be reinforced by counseling the participants after the CPET. In the present study, the influence by verbal persuasion was eliminated by the use of standard phrases of encouragements throughout the test. Additionally, limited information about the participant’s performance was given until after the second post CPET questionnaire was completed.

Dimensions of SE: Task, Coping, and Scheduling SE.

SE has been found to relate to the confidence for performing specific behaviors in specific situations, and SE in one behavior may, therefore, not directly transfer to higher SE in other behaviors, situations, or activities (Bandura, 1997). On the other hand, when the situations or behaviors share crucial features and requires similar skills, generalization of SE from one behavior to another may occur. As an example, Ewart et al. (1983) found SE to be a good predictor of performance on the CPET. The performance on the CPET was thereafter well reflected in modified SE judgments. Interestingly, the modified SE judgments were found to be more accurate predictors of subsequent home activity than the physiological outcomes of the CPET (Ewart et al., 1983). Therefore, different CPETs, such as treadmill – and cycle CPETs, may or may not influence SE for PR, exercise, and/or physical activity similarly.

Different types of SE may serve different purposes depending on the activity or behavior involved, and the differentiation has been found to be particularly relevant to exercise (e.g., Blanchard, Rodgers, Courneya, Daub, & Knapik, 2002; Maddux, 1995; McAuley, et al., 2003). Intention to initiate exercise and exercise adherence are likely under the influence of different dimensions of SE (W. Rodgers & Sullivan, 2001), and thus, the influence of task, coping, and scheduling SE may differ depending on the stage of behavior change.

Task SE.

Task SE has been found to be important at the stage of intention to- or initiation of exercise, and out of the three dimensions of SE, task SE would be expected to be most influenced by the CPET. Correspondingly, we did observe a significant change in task SE from pre CPET to post CPET for both tests, and the successful mastery experience was observed regardless of exercise modality and sex. An increase in SE was observed after both the first and second CPETs, and even though the increase in SE seemed to be greater with the first test, the increase was not significantly different between the tests.

Coping and Scheduling SE.

Even though coping and scheduling SE would be expected to be more influenced by the PR program, where the actual experience of scheduling and overcoming barriers to exercise are tested over time, both coping and scheduling SE were significantly improved as a result of the CPETs. However, as expected the change in SE following the CPET was greater for task SE than coping and scheduling. Similarly to task SE, the increase in coping SE and scheduling SE were not influenced by the exercise modality. The increase in coping and scheduling SE can potentially relate to the positive mastery experience of performing the elemental tasks of the CPET, and thus believing that these elemental tasks can be performed in the face of challenges and time management as well. As mentioned previously, coping and scheduling would normally be expected to increase with maintenance of behavior rather than with a single bout of exercise. Correspondingly, for coping SE, we did not see any additional changes as a result of the second test, and any further increase in coping SE would be expected to occur first as a result of the PR program. A similar finding was expected for scheduling, but rather, a significant difference was found for scheduling SE between test one and two. Perhaps the second test already could reassure the ability to schedule time for exercise. These findings, however, needs to confirmed through future research studies.

SE and Feeling state.

Interestingly the patients were feeling worse at the end of the treadmill test despite still having similar confidence after both the treadmill and the cycle ergometer tests. Perhaps feeling worse at the end of the test (as on the treadmill) could lead to stronger confidence for exercise, as greater challenges can be associated with stronger mastery experiences.

State-Anxiety.

The CPET situation may be experienced as threatening to the COPD patients because of the unfamiliarity of the clinic, the personnel, and the expectations, and even more so, the exercise and the likelihood of experiencing shortness of breath (Eakin, et al., 1992). The confidence for exercise may be altered by negative affective experiences like anxiety (Ewart, 1995). As the patient may feel "out of control", they may arouse themselves to elevated levels of stress. The prevalence of anxiety has been found to be high in COPD patients (Brenes, 2003; Di Marco, et al., 2006), and worse in women compared to men (Di Marco, et al., 2006). People with higher trait anxiety are more likely to perceive stressful situations threatening and thus, respond to the CPET situation with elevated levels of state anxiety. For the STAI, a cut off value of 45 has been used to dichotomize patients into low- and high anxiety groups (Di Marco, et al., 2006). As our patients had anxiety scores ranging from 35 to 40, they did not appear to have "clinical anxiety". However, as predicted we did observe increased state-anxiety scores prior to the fist CPET, showing that the anticipation of the CPET was stressful. After the first test and in relation the second test, however, the level of state-anxiety remained stable, showing that the initial state-anxiety score most likely did not represent the participant's "normal" level of state-anxiety. Future studies should look into the relation between state-anxiety and SE scores. The scores would be expected to correlate such that a person with high levels of state-anxiety probably would score low on SE, and thus if a small change in anxiety is observed after the CPET, a smaller change in SE would also be expected and vice versa.

Arousal and affective responses.

Arousal states and affective responses did not differ between pre and post measurements, or between the first and second test. Thus, it seemed as the CPET assessment situation did not influence how the participants were feeling in general at that particular time, and also, it shows that anxiety and arousal are two different things. Even though the patients were state-anxious before the first CPET, they did not arouse themselves to elevated levels of stress.

Overall physiological findings.

The CPET was perceived as a positive mastery experience in these participants, with increased task, coping, and scheduling SE. There were, however, no additional benefits of performing the second CPET.

Responses to treadmill-CPET and cycle-CPET in men and women

Historically, more men than women were diagnosed with COPD, but changes in women's life style behaviours over the last few decades have changed this trend and more women are now being diagnosed with this airway disease. Despite this, women have seldom been included in studies comparing exercise modality and CPET responses in COPD, or if women were included, sex differences have not been discussed (Christensen, et al., 2004; Hsia, et al., 2009).

COPD is a heterogeneous disease, and anatomical differences between men and women may influence susceptibility, disease progress, functional capacity, and experience of symptoms. Based on previous research we believed that men would tolerate higher metabolic demands and achieve greater peak power output and VO_2 compared to women with both treadmill- and cycle-CPET. We also predicted that women would become more ventilatory limited and hyperinflated than men, especially with the cycle-CPET. As a result of this we expected the women to rate their levels of breathing discomfort higher, and similarly, we expected women to rate their levels of leg discomfort higher than men, especially with the cycle-CPET.

Patient characteristics.

We did not match our men and women for age and lung function during the recruitment phase or during the stage of analysis. We observed that the male subjects were older than the females, and they had a greater decrease in FEV_1, but none of these findings were significant. All anthropometric data, besides height, were similar for men and females. As the men were significantly taller than the women, greater lung volumes (vital capacity and total lung capacity) were seen in the male subjects. No between sex differences were observed for either BMI or mid-thigh circumference, as both men and women had slightly elevated BMI above normal (>25). There was no reason to believe that our subjects were at a stage in their disease process were muscle wasting occurs.

Physiological responses to CPET in men and women.

Previous findings comparing VO_{2peak} in men and women, have found VO_{2peak} to be 10-20% lower in women across the age span (Milani, Lavie, Mehra, & Ventura, 2006). We found similar differences in our study, but as we did not match our male and female subjects for age these findings were insignificant. Interestingly, we found no sex differences in peak power output- and VO_{2peak} responses between treadmill- and cycle-CPET. As for the overall group, both men and women achieved greater peak power output with the treadmill-CPET. However, when looking at Figure 3-3a and 3-3b, the differences in these peak values between the treadmill- and the cycle-CPET seemed to be greater in women. A continuous increase in the women's VO_2 values was observed up until peak exercise with both CPETs, but the VO_2/power output slope seemed to be slightly blunted with the treadmill-CPET. This trend, although not significant, can potentially be related to handrail holding on the treadmill-CPET. The incline on the treadmill was determined by the participants' body weight, and even though there was no significant difference between men and women's body weight, women were on average 12.3kg lighter than the men. Thus, the lighter women had to walk on a steeper slope on the treadmill at the same work stage. Participants walking up a greater incline might have held on tighter in order to avoid sliding backwards, but as there was no measurement of the pressure exerted on the handrails, only speculations can be made. The blunted VO_2/power output response in women may indicate an overestimation in peak power output in the female participants as a result of the steeper treadmill incline.

Decreased muscle mass, and thus muscle strength, is often seen in women compared to men. Lower muscle mass in women was expected for our study as well, and this was believed to be one of the reasons for why the women could be more ventilatory limited than the men. However, our crude measure of muscle mass (i.e. mid-thigh circumference) was not different between men and women, and correspondingly, we found no difference in the ventilatory responses between the sexes. Rather, it appeared that the slope of change in IC in men were steeper from baseline to peak exercise compared to the women. These differences could potentially relate to the greater absolute lung volumes in men, but perhaps it could relate to the slight difference in disease severity between men and women as well.

Despite the differences in operating lung volumes between men and women, there was no difference in the level of breathing discomfort between men and women with either CPET. A difference was seen though, between men and women's rating of leg discomfort. Men rated their leg discomfort to be similar for both CPETs, but the women did report, as predicted, greater leg discomfort with the cycle-CPET compared to the treadmill-CPET. Women's leg discomfort with cycling, however, was similar to the level of leg discomfort the men reported for both tests. Men also had a more gradual increase in leg discomfort, whereas the women had small changes initially with a great increase in leg discomfort toward peak exercise for both tests. As women were walking up a steeper incline on the treadmill, it would have been expected that their leg discomfort would be correspondingly greater. Perhaps, if the women were holding on to the handrails more tightly with progressive exercise, that the stress on their legs was lowered and thus their rating of leg discomfort were lower.

Psychological responses to CETP in men and women.

Women have previously been found to have lower confidence for exercise than men (Blanchard, et al., 2002), and even though our data demonstrate some trends that differences between men and women exist, the only significant difference between men and women was for scheduling SE. Elderly people may have less issues with scheduling than younger people, as younger people keep busier with work, family, and other obligations. In this study, however, the women were younger and more women than men were still working, but they still had increased levels of scheduling SE compared to the men. Further investigations with larger sample sizes are needed to evaluate this further.

Differences between men and women.

Overall, it seemed that the differences we expected to occur between men and women did not occur in this group of COPD patients. Thus, based on both the physiological and psychological results in this study, we were unable to see whether one exercise modality was better to use for CPETs in male and female COPD patients. Future studies should match men and women better for lung function (absolute FEV_1), as this might influence the psychological findings (i.e., ventilatory response, change in IC, exertional symptoms). Future studies should also examine how the psychological responses are influenced by working status, previous exercise and exercise test experience

Limitations

A great portion of the COPD patients referred to the Breathe Easy program was excluded from this study for reasons such as disease severity (i.e., long term oxygen users), orthopedic limitations (i.e., knee, hip and back pains, use of 4-wheel walkers), and language difficulties. This can probably explain why resting lung function (FEV_1) was higher and thus COPD disease less severe in our participants compared to other studies comparing cycle-CPET and treadmill-CPET (Christensen et al, 2004; Hsia et al, 2009; Mathur et al., 1995; Palange et al, 2000). The findings and responses observed in our study can therefore not be generalized across patients entering a PR. However, our findings overall were similar to what has been found in COPD patients previously, with examples such as increased ventilatory response with cycle-CPET, greater leg discomfort with cycle-CPET, greater oxygen desaturation with treadmill-CPET, and changes in operating lung volumes (decreased IC) with both exercise modalities. These typical findings could potentially have been more prominent had more severe patients been included in the study, and larger differences could have appeared between treadmill- and cycle-CPET.

Additionally, the comparisons of responses to treadmill and cycle-CPET between men and women were made without matching for disease severity (FEV_1), smoking history, age, and/or height. We expected the women to be more ventilatory limited, have greater change in operating lung volumes, and rate their level of breathing and leg discomfort greater compared to the men. This study did not reveal these differences. However, more men than women were included in the study, and the men were older and had more severe lung disease than the women (although these differences were not significant). Differences and similarities between male and female subjects thus could have been better evaluated if matching had occurred.

Although different choices could have been made for inclusion of participants in the study, these subjects were chosen purposely to compare the “linear” treadmill-CPET with a more traditional cycle-CPET, and thus to evaluate the usefulness of these tests in the clinical practice (in patients with mild to moderate COPD). The goal was to have the participants perform the treadmill-CPET, which includes walking up a progressively increasing incline, without holding on to the handrails and less severe COPD patients were for that reason chosen. Our study resulted in what appeared to be linear increases in physiological responses (i.e., VO_2, VCO_2, HR) to exercise. However, a potential overestimation of peak power output was observed with the treadmill-CPET, especially in women. This could be a result of having to allow the participants to rest their hands on the handrails. Thus, despite our participants being moderate COPD patients, they were unable to walk on the treadmill without holding on. The CPETs in our study were performed as part of a clinical evaluation before a PR program, and as would be expected of many participants entering a PR program, our participants had limited experience with walking on a treadmill. When considering the whole group of PR participants, including patients with more severe lung disease and lower functional capacity, walking without holding on to the handrails can be problematic in a great portion of these patients. Familiarization to the test equipment is often noted to be beneficial prior to a CPET, but we did not include any time for this as we wanted to replicate a clinical setting and it is questionable whether this is practicable in most clinical practice. Even though a slight overestimation of peak power output may be expected with the treadmill-CPET, the low initial metabolic demand and what appeared to be a linear increase in metabolic demand over the course of the test still made the protocol useful for appropriate interpretations of exercise capacity and exercise limitations in these COPD patients.

Another aspect of the CPET protocols that may be important to discuss was the choice of work rate increments for both tests. The work rate increments on the treadmill- and cycle CPET were based solely on disease severity (i.e. FEV_1) in our study. Although we achieved what appeared to be linear increases in power output with both CPETs, the test durations were highly variable with a few tests lasting only ~ 4 minutes. Short tests like this make test interpretations more difficult and unreliable. As exercise capacity can vary between COPD patients with similar FEV_1 values, an inclusion of functional capacity estimates and MRC scores to predict peak power output in addition to FEV_1 values, could potentially increase test durations and thus improve test interpretations.

Hypoxemia with exercise and physical activity is a frequent finding in COPD patients, and the measurement of oxygen saturation is therefore important for detecting the need for additional oxygen therapy with physical activity. We used a non-invasive method (i.e., finger probe oximeter) to measure oxygen saturation throughout the test. This is a common method of measurement in clinical practice. However, research has found this measurement to be highly unreliable, with measurement errors of 2% (Powers et al., 1989; Yamaya et al., 2002). Although oxygen saturation was significantly greater with our treadmill-CPET, the actual difference was only 1.1%, which is within the range of measurement errors. We did experience some difficulties with noise during both the treadmill- and cycle-CPET, but as we did not have invasive measurements we could not evaluate whether the data was reliable or not. Even though invasive methods of measurement are more reliable it is not practicable to perform invasive measurements on all participants in the clinical setting.

The positive increase in confidence for exercise as a result of the CPET, regardless of exercise modality, speaks to the appropriateness of the challenge experienced both on the treadmill-CPET and the cycle-CPET. There was, however, no measurement of how well the participant's were able to cope with more "acute" stressors and barriers during the test. Such barriers could include leg discomfort, breathing discomfort, discomfort from mouthpiece and noseclip, seat discomfort, pains, fear, and state anxiety. Breathing discomfort in particular, may play a significant role for how confident the COPD patients are for managing the rest of these barriers. Perhaps the SE instrument could be adopted to include an under-section of coping SE, assessing these "acute" barriers, as these could influence a successful versus a negative mastery experience. Perhaps relations could be found between these barriers and SE for exercise (task, cope, and scheduling), anxiety, affect, and arousal.

Appropriate CPET durations are, as mentioned previously, important for evaluation and interpretation of data, and the variability in exercise duration in our study therefore made data analysis more difficult. In order to keep all the participants in the analysis, five work stages were chosen for comparison of absolute work stage values, and work stages were chosen for comparison of values in relation to measurements of VO_{2peak}. The absolute work stages chosen for analysis was baseline, work stage 1, 2, and 3, and peak exercise. As a few participants performed exercise tests of ~4 minutes, these patients would have been lost if more work stages had been included. These patients, however, represented the most severe COPD patients in our group, and were important to include. Because these absolute work stages covered the entire test for a participant who completed the test in four minutes, but missed everything beyond the 4th minute of exercise until peak exercise in all the participants that completed CPETs of longer duration than 4 minutes, the data were also analysed in relative terms. The three work stages included in the analysis was 40%, 80%, and 100% of VO_{2peak}. Again, these three work stages were analysed because all the participants would then be included. Care must be taken though, when comparing the absolute and relative analysis, as these are not identical time points for all the participants. Whereas the analysis of the absolute work stages gives a better picture of what is happening early in the test, the analysis of the relative work stages gives picture of what is happening towards peak exercise. Preferably, if the exercise durations had been more similar, more work stages could have been analyzed and thus better comparisons could be made throughout the whole test.

Future recommendations

Future studies should evaluate what the most appropriate method for determining work rate increments in men and women with COPD, across a wide range of disease severity. Thereafter, an evaluation of the usefulness of the “linear” treadmill protocol in clinical practice should be made, with a comparison to a standard cycle-CPET. This should also be done in a greater range of COPD patients, including e.g., severe patients on oxygen therapy and those with limited functional capacity for other reasons than COPD. Thus, this evaluation should be based out of clinical practice, including “typical clinical patients”. Included in this analysis should be an evaluation of the effect of handrail support, and the importance of this for the clinical evaluation. Similarly, effects of familiarization with both treadmill and cycle exercise should be evaluated (especially for the ability to walk up an incline without holding on to the treadmill).

As the invasive measurement of oxygen saturation may not be very practicable in the clinical practice, future studies should identify who should be tested invasively and who can be tested non-invasively, and how to differentiate or screen the two groups.

Additional research should look into the effects of “acute” stressors or barriers during the CPET, and how this may influence the mastery experience of the CPET. Relationships to SE for exercise, state-anxiety, arousal and affect should be evaluated, and interventions to increase the participant’s confidence for overcoming such barriers should be identified.

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