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The Effects of Respiratory Muscle Warm-up on Exercise Performance and Pulmonary Functions

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THE EFFECTS OF RESPIRATORY MUSCLE WARM-UP ON EXERCISE PERFORMANCE AND PULMONARY FUNCTIONS

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PREFACE

This dissertation was a collaboration of four experiments conducted in cooperation between the Department of Kinesiology at Louisiana State University, Baton Rouge, Louisiana, (degree granting institution) and Nicholls State University (experimentation site). The first two experiments were pilot studies. The first was to establish the preliminary testing capabilities of the laboratory and that data was presented at The American College of Sports Medicine National Meeting in May of 2014 (milestone requirement) and the second was used to determine which of the breathing warm-up techniques (inspiratory, expiratory, and combine) would be the most adventitious to use in the primary experiments. The second two experiments were conducted in two phases (Non-Asthmatic males and Asthmatics). Chapter 1 provides a critical review of the literature (General Exam), presentation of the problem, and discussion of the rationale for experimentation. Chapter 2 is comprised of the four experiments. Chapter 3 presents information on an overall conclusions and suggestions for future investigation.

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ABSTRACT

Effect of a Specific Respiratory Warm-up on Run Performance, Pulmonary Functions, and Rating of Perceived Breathing

The purpose of this study was to evaluate the effect of a respiratory warm-up for five minutes using an inspiratory/expiratory (IEC) device on pulmonary function (PFT) (FVC, FEV_1, FEF 25-75%, PEF), rate of perceived exertional (RPE) breathing, and performance time [300 yard shuttle run (300y) and 1.5 mile run (1.5m)] in asthmatics and non-asthmatics. Ten non-asthmatics males (22.6±7.4 years) participated in phase I, twenty non-asthmatic males (24.2±9.8 years) in phase II, and five asthmatics (20.8±3.2 years) in phase III of this study. The Phase I pilot study examined three breathing warm-up (inspiratory only, expiratory only, and combined IEC). Results suggest the IEC produced the most favorable responses (greatest system stress, highest recovery data). In phase II and III, subjects performed initial resting PFT (asthmatics performed an additional five-minute post medication resting PFT), followed by five-minutes of a no-warm-up controlled condition (CC) or five-minutes of IEC. After completion of the CC or the IEC, subjects rested for five-minutes and then performed either a 300y or a 1.5m for time. After the runs, subjects performed one-minute recovery intervals of PF and RPE up to 15-minutes as well as five-minute intervals of PFT up to 15-minutes. Paired sample t-tests were calculated to compare CC to IEC across the two runs with statistical significance for these correlations set at $p \leq 0.05$*. The results indicated that non-asthmatics benefited from the IEC and improved performance by 3.2% (average of 25 seconds) in the 1.5m over the CC [M=13.1075 v. 12.6830, SD=2.19429 v. 1.85474, p= 0.044*]. Asthmatics increased their FEV_1 at five-minutes of recovery after the IEC verses the CC for the 1.5m [M=3.3120 v. 3.4280, SD=0.51339 v. 0.54929, p= 0.019*]. The results suggest that a respiratory warm-up could be beneficial by improved performance and increased pulmonary functions to asthmatics and non-asthmatics alike.

CHAPTER 1. INTRODUCTION

1.1 Purpose

The purpose of this review is to identify the value of a specific respiratory warm-up on exercise performance and the respiratory system, particularly the respiratory muscles and bronchial airways in healthy individuals. Many exercise physiologists believe that the respiratory system has little to no effect on limiting exercise performance in healthy individuals or athletes (A. McConnell, 2009), yet the respiratory system encounters several challenges during intense exercise. One example is that the regulation of alveolar partial pressure of oxygen (O_2) and carbon dioxide, achieved by a considerable increase in alveolar ventilation, minute ventilation (VE), often 20 times the resting value in humans. This is achieved by the capacity of the respiratory muscles to not only generate force to alveolar ventilate but also by limiting excessive physiological cost on the system during exercise (Guenette & Sheel, 2007). A second example of the challenges the respiratory system must overcome is the ability of the bronchial (intra-thoracic) airways to maintain patency to allow the increase flow rate needed during active expiration often seen in intense exercise. During high intensity exercise, the bronchial airways occasionally do present a significant limitation to expiratory flow, thereby causing dynamic hyperinflation, increased respiratory muscle work, and VE limitation (Forster, Haouzi, & Dempsey, 2012). Research has focused on these functions (muscular work/fatigue and airway patency) of the respiratory system to determine respiratory limitation during and after exercise. A review of these areas of function will follow, as well as possible ways to overcome and/or lessen the challenges imposed on the respiratory system during exercise.

This review has four sections. The first will serve as an overall introduction to factors relevant to this review of the respiratory system during and following exercise, exercise induced bronchoconstriction (EIB)/exercise induced asthma (EIA), and an examination of expiratory

flow limitation (EFL). The second will examine methods to train the respiratory system for exercise performance. The third will examine the use of various types of warm-up that may be used to take advantage of a so-called “refractory period.” The final section will discuss the future direction of research based on the areas identified during this review.

1.2 Respiratory System: Challenges with Exercise

For the purposes of insight to the control of breathing mechanisms as seen during exercise, one should review the information found in Forster et al. (2012) and others like Babb, Wood, and Mitchell (2010) and Miyamoto (1990). The mechanical work necessary to ventilate the lungs at rest and during exercise has many mechanisms to involve elastic and non-elastic work with some sub-components including inertial forces, gravitational forces, and distortional forces of the chest wall (Guenette & Sheel, 2007). During heavy exercise, additional mechanical constraints are placed on the respiratory system’s ability to increase VE, including the capacity of the inspiratory muscle pump to generate negative pleural pressure and the capacity of the intra-thoracic airways to maintain patency that allows for increases in flow rates during active expiration (Forster et al., 2012). The total mechanical work is the sum of all of these factors. An increase in VE with progressive exercise to exhaustion creates a disproportionate increase in mechanical work and the O_2 cost of breathing. However, in cases of healthy individuals, the dynamic capacity of the inspiratory/expiratory muscles for force generation probably never limits the VE response to exercise (Guenette & Sheel, 2007). More specifically, only about one-half of the inspiratory muscle’s dynamic capacity is reached at peak exercise in young adults. As much as 80-90% of the inspiratory muscle’s dynamic capacity needed by highly trained athletes to generate the required intra-pleural pressures requires twice the metabolic cost (O_2) and VE responses as that seen in untrained individual (Forster et al., 2012).

An often-overlooked ingredient to possible limitation is how the mechanical work of breathing has both sensory and metabolic repercussions. The perceived work of breathing contributing to how hard the exercise feels and the demands the mechanical work of breathing places on the circulatory system for blood (O_2) to sustain muscle contraction are examples of the sensory and metabolic consequences (A. McConnell, 2009). It has been suggested that the metabolic and circulatory cost of a high mechanical work of breathing during maximal levels of VE can amount to 8-10% of the VO_{2max} and cardiac output in the untrained individual and up to 14-16% of VO_{2max} and cardiac output in highly-trained individuals (Aaron, Johnson, Seow, & Dempsey, 1992; Harms, McClaran, et al., 1998). These findings may represent the respiratory system's inability to sustain airway patency in the face of maximal or near maximal workloads, creating high VE demands and variations in possible expiratory muscle fatigue because of changes in dynamic hyperinflation seen in EFL.

The primary muscle of active inspiration in humans is the diaphragm. The diaphragm is a large, dome-shaped muscle separating the abdominal and thoracic cavities and innervated by the phrenic nerve. It possesses unique characteristics that make it the most fatigue resistant (very high aerobic enzymatic capacity, rich sources of blood supply, and resistant to vasoconstriction) of all the skeletal muscles (Miller, Hemauer, Smith, Stickland, & Dempsey, 2006). Other muscles that can assist the diaphragm with inspiration are the external intercostal, scalene, and sternocleidomastoid (accessory muscles). As ventilation increases the respiratory muscles are recruited. During quiet breathing, there is little or no muscle contraction/relaxation involved in expiration, and the elastic recoil of the lungs in healthy individuals drives the process. The abdominal muscles and the internal and innermost intercostal muscles assist forced or active expiration that occurs during heavy intensity exercise (Guenette & Sheel, 2007). The recruitment

of the diaphragm during exercise may be assessed indirectly through measurement of trans-diaphragmatic pressure (Pdi), surface electromyography (EMG), and use of bilateral phrenic nerve stimulation (BPNS) with Pdi. Pdi is the measured difference between gastric and esophageal pressure and can be assessed during BPNS (a bilateral and supra-maximal stimulation of the phrenic nerve via electrical/magnetic stimulation) (Guenette & Sheel, 2007; Johnson, Babcock, Suman, & Dempsey, 1993). From research using these techniques, it is believed the diaphragm is recruited in proportion to the increases in VE with increasing intensity of exercise (Johnson et al., 1993). Others have proposed that the Pdi plateaus in the face of increasing VE, thereby suggesting that accessory muscle recruitment plays an active part in the total pressure generated by the inspiratory muscles (Johnson et al., 1993). Regardless of the contribution of the diaphragm and the accessory muscles, the force output required to sustain VE during intense exercise requires significant muscle work (O_2 demand) and a significant proportion of the cardiac output to meet the applied intensity. Considering the factors of high O_2 demand, required cardiac output, and high work of breathing, it seems plausible that the diaphragm and accessory muscles may be susceptible to fatigue (Guenette & Sheel, 2007). Fatigue in respiratory muscles is a condition in which there is a reduction in the capacity for developing force and/or velocity of a muscle, which is caused by activity under load and which is reversible by rest (Macklem, 1990; "NHLBI Workshop summary. Respiratory muscle fatigue. Report of the Respiratory Muscle Fatigue Workshop Group," 1990). The diaphragm will show significant fatigue during sustained exhaustive exercise with intensities greater than 80-85% of VO_{2max} (Johnson et al., 1993; Miller et al., 2006). Exercise-induced diaphragmatic fatigue is caused by high levels of diaphragmatic work that must be sustained throughout high-intensity exercise. With prolonged high intensity exercise, hyperventilation is present throughout,

suggesting that diaphragmatic fatigue does not impede the ventilator response (Miller et al., 2006). However, indirect evidence of pressure readings suggests that the fatiguing diaphragm reduces its force generation during the late stages of sustained endurance exercise. This causes the accessory muscles of inspiration and the expiratory muscles to become more dominant in maintaining respiratory muscle work and hyperventilation. This increased use of expiratory muscles helps create a reduction of end-expiratory lung volume, which increases intra-abdominal pressure, thus allowing the diaphragm to lengthen, preserving its maximal ability to force generate (Forster et al., 2012). Some researchers have attempted to identify if respiratory muscle can be fatigued.

When a proportional assist ventilator (PAV) was used during exercise, fatigue of the diaphragm was prevented (Babcock, Pegelow, Harms, & Dempsey, 2002). These findings do suggest respiratory muscles can be fatigued during maximal exercise. Research by Babcock et al. (1995) evaluated resting subjects as they voluntarily mimicked the magnitude and duration of diaphragmatic work seen during endurance exercise. They noted that fatigue did not occur until diaphragmatic work increased to double the work required during maximal exercise. This would suggest that the diaphragm must compete with the loco-motor muscles for the available cardiac output during heavy-intensity exercise, leaving the diaphragm with inadequate O_2 transport, thereby creating a fatigued state (Miller et al., 2006). This fatigued state likely activates meta-boreflexes from within the inspiratory and expiratory muscles, which increase sympathetic vasoconstrictor outflow, leading to a redistribution of cardiac output (Harms, McClaran, et al., 1998).

There are complex mechanical effects of intra-thoracic and intra-abdominal pressure on stroke volume and cardiac output with respiratory muscle fatigue (Forster et al., 2012). EFL is

accompanied by high expiratory pressures, which may approach or exceed the critical closing pressure of the airways with exercise, which can result in increased left ventricular afterload and reduced stroke volume (Miller, Pegelow, Jacques, & Dempsey, 2005). If inspiration is accomplished by the diaphragmatic contraction alone, then the resulting increase in intra-abdominal pressure with the downward movement of the diaphragm impedes the exercising lower limb venous return (Forster et al., 2012). Miller et al. (2005) suggests that this reduced venous return is recovered during expiration with little net effect on reduced total venous return. As reviewed earlier, during heavy sustained exercise, respiratory muscle blood flow may consume 8-10% of the VO_{2max} and cardiac output in the untrained individual and up to 14-16% of VO_2 and cardiac output in highly trained individuals, thus affecting blood flow for the working limb muscles (Aaron et al., 1992; Harms, McClaran, et al., 1998; McClaran, Harms, Pegelow, & Dempsey, 1998).

Harms et al. (1998) set out to test the effect of respiratory muscle fatigue on sympathetic outflow vs. exercising limb blood flow by altering the work of breathing during high intensity cycling exercise. They used resistive loading and a PAV unloading of the respiratory muscles to manipulate the work of breathing. Their results suggest that exposure of the respiratory muscle to a loaded state produced a reflex vasoconstriction reducing blood flow to the exercising limb. Conversely, when the respiratory muscles were unloaded with the PAV, a state of increased blood flow (dilation) existed. These changes in limb blood flow indicate a competitive relationship exists between the muscles of locomotion and the muscles of respiration for limited cardiac output (Guenette & Sheel, 2007). Research on time to exhaustion (performance) using the same loading and unloading of the respiratory muscles as discussed above showed that loading via resistive devices produced a decrease in time to exhaustion and unloading with a

PAV increased time to exhaustion averaging ±14-15% (Harms et al., 2000). These results suggest that increased performance (time to exhaustion) effect may be explained with reduced dyspnea perceptions secondary to reduced respiratory muscle work (Miller et al., 2006).

The respiratory system must contend with many challenges during exercise. The most notable challenge is the mechanical work of the respiratory muscles because of the necessity to ventilate the lungs at rest and during exercise and the capacity of the intra-thoracic airways to maintain patency that allow for increases in flow rates during active expiration. During exercise the increase in VE with progressive exercise to exhaustion creates a disproportionate increase in mechanical work (as listed above), hence an increase in O_2 cost of breathing. This increase O_2 cost from mechanical work to achieve increase in VE during heavy sustained exercise creates competition for cardiac output, thereby affecting blood flow for the working limb muscles and, thus, causing fatigue in both muscle groups (respiratory muscle and working skeletal limb muscles). Could exercise performance be enhanced if the challenges placed upon the respiratory system were reduced by changing the pre-exercise condition of the same respiratory system?

1.3 Exercise and the Effects on Pulmonary Function

The second described challenge facing the respiratory system during intense exercise is the ability of the bronchial (intra-thoracic) airways to maintain patency to allow increased flow rate during active expiration often seen with high-intensity exercise. As discussed earlier, during high intensity exercise, the bronchial airways occasionally do present a significant limitation to expiratory flow, thereby causing dynamic hyperinflation, increased respiratory muscle work, and VE limitation (Forster et al., 2012). This challenge to maintain airway patency may be assessed using various breathing maneuvers, which will be reviewed here.

Spirometry is a simple method of assessing lung function by measuring the volume of air that the subject can exhale from the lungs after a maximal inspiration. It is often used to diagnose individuals with Chronic Obstructive Pulmonary Disease (COPD) and is the best way to detect airway obstruction (Ruppel & Enright, 2012; "Spirometry for the Health Care Provider," 2010). Specific measures derived from spirometry (directly and indirectly) include the forced vital capacity (FVC), slow vital capacity (SVC), forced expiratory volume in one second (FEV_1), FEV_1 /FVC ratio, forced expiratory flow 25%, 50%, 75%, 25-75% (FEF 25%, FEF 50%, FEF 75%, and FEF 25-75%), peak expiratory flow (PEF), and peak inspiratory flow (PIF) (Ruppel & Enright, 2012). Another measure that is often performed after spirometry is the maximal voluntary ventilation (MVV), which can be used to derive a breathing reserve value during maximal exercise testing (Bender & Martin, 1985; Hill, Jacoby, & Farber, 1991; Johnson, Weisman, Zeballos, & Beck, 1999). Some other measures use different devices to assess maximal inspiratory pressure (MIP or PI_{max}), and maximal expiratory pressure (MEP or PE_{max}) (Coast et al., 1999; Haverkamp, Metelits, Hartnett, Olsson, & Coast, 2001). A more difficult measure because of the nature and bulkiness of the equipment needed is the determination of total lung capacity (TLC), residual volume (RV), fraction of residual capacity (FRC), and expiratory reserve volume (ERV) (Chapman, Allen, & Romet, 1990; Ruppel & Enright, 2012). Recent studies have used many of these measures separately or in various combinations to assess respiratory muscle weakness and EFL.

The most commonly used spirometry values for assessment of respiratory muscle weakness/ fatigue and EFL have been the measures of FVC and FEV_1 (Coast et al., 1999; Haverkamp et al., 2001; Hill et al., 1991; Mahler & Loke, 1981; O'Kroy, Loy, & Coast, 1992). The second most commonly used measures are the MIP and MEP (Coast et al., 1999;

Haverkamp et al., 2001; Hill et al., 1991; O'Kroy et al., 1992; Ozkaplan, Rhodes, Sheel, & Taunton, 2005). Few studies use MVV, TLC, RV, and ERV to assess EFL and possible respiratory muscle fatigue (Bender & Martin, 1985; Cordain, Rode, Gotshall, & Tucker, 1994; Nourry, Deruelle, et al., 2005a).

Haverkamp et al. (2001) studied the effect of expiratory muscle fatigue on pulmonary functions in eight (seven male and one female) healthy human subjects exposed to an expiratory fatigue (EF) trial (loaded breathing protocol). Pre and post-trial recovery (0, 5, 10, and 15-minutes) measures were compared to a control trial (CT). The findings suggest MEP was the only measure to see significant change between EF trial pre/post and CT that remained unchanged. This finding is not surprising because the EF trial termination was when the MEP value fell below 80% of the pretrial value. It also seems plausible that the EF trial was not of significant intensity or duration (average time to trial end was seven-minutes) to elicit a change in expiratory flow.

Hill et al. (1991) studied a group of triathletes to see what pulmonary function measures changed during an endurance triathlon. Pulmonary functions were obtained after each event, following the completed event, and with one day of recovery. Twelve male subjects completed the 3.8 km swim, 180 km bike, and the 42 km run with an average finishing time of 12-hours 45-±90 min. Following the completion of the triathlon, significant declines from baseline were noted in the FVC (7.1%), FEV_1 (8.4%), FEF 50% (18.6 %), FEF 25-75% (15.2%), but no change in MVV or the other FEF measures, ratio, and/or PEF. The PI_{max} did not decline after the swim, but decreased significantly after the bike (26%). That reduction continued after the run, but the PE_{max} showed no significant reduction at any time. The FEV_1 was the only to still be considered significant the morning after (a proximally, 12-hours). These results suggest the

duration (>12-hours) of the exercise is an important variable reflective of declines in some pulmonary function measures. It remains to be determined at what time interval these variables return to baseline and the suspected causes of such declines.

Mahler and Loke (1981) studied pulmonary function in fifteen ultramarathon runners before and after (10 to 15-minutes and 2.5-hours) a 80.6-100km (50 to 62.2-mile) road race with a mean running time of 7-hours 42-minutes (in 80.6 km). The results revealed a significant post-race decline in FVC (12.4%), FEV_1 (9.5%), FEF 50% (28.4), PEF (13.7%) with values improving after 2.5 hours of recovery. The authors believe there are an airway obstructive component (because of reduction in flow rates) and a respiratory muscle fatigue component (because of recovery after rest and nourishment). These results are similar to the results obtained by Hill et al. (1991) that supporting the value of exercise duration producing declines in pulmonary function measures. However, this study showed a return to baseline values within 2.5 hours of recovery.

O'Kroy et al. (1992) examined the before and after (5, 10, 30 minutes) exercise pulmonay function of nine (seven males and two females) active runners following exercise at three different intensity and durations on a treadmill. The purpose of the study was to determine which intensity and durations elicit changes in FVC and if these changes could be related to respiratory muscle fatigue. The intensity and durations protocols were as follows: 1) a graded maximal test to exhaustion (7-14 minutes duration); 2) a seven minute test at 90% of VO_{2max}; and 3) a 30 minute test at 60% of VO_{2max}. The MEP measure approached significance at 10 minutes posttest with no difference observed between intensities and MIP showed no difference between both time or intensities. FVC was different between times but not intensities and was decreased at five and ten minutes as compared to pre-values. FEV_1 was significantly reduced at five and ten

minutes as compared to pre-values across intensities. The authors feel the data suggest a combination of exercise duration and intensity may be needed to elicit changes in pulmonary function after exercise and that expiratory muscle fatigue may be a factor that causes the reduced FVC. Something worthy of bringing to attention (no mention in the article) is the FVC and FEV_1 increased (to near significance) for the 30-minute, 60% of VO_{2max} intensity protocol (from Figure 1) at 30-minutes posttest, suggesting a possible aiway dialation taking place.

Coast et al. (1999) examined the effects of a maximal exercise trial (progressive maximal cycle ergometer test) and a voluntary isocapnic hyperpnea (VIH) trial (mimicking frequency and depth of breathing at maximal exercise) on pulmonary functions pre and post-trial (0, 5, 10, 15 minutes) from eleven (six males and five females) healthy subjects. A significant decrease in FVC (7%) was observed immediately following the exercise trial, and the MIP (15%) remained reduced for 15-minutes post-trial. The MEP and FEV_1 were unchanged with the exercise trial and all four measures were unchanged in the VIH trial. The authors suggest the data indicate pulmonary function and respiratory muscle strength may be altered following exercise but not by a similar trial of VIH. They further suggest the exercise effects on pulmonary functions are independent of respiratory muscle work done.

Ozkaplan et al. (2005) studied the relationship between respiratory muscle fatigue and recovery (1, 2, 3, 4, 5, 10, and 15-minutes) using the MIP following exercise to VO_{2max} in moderately trained males (18) and females (16). The MIP significantly decreased equally in males (16%) and females (15%) from pre-data and remained reduced in both genders throughout 15 minutes of recovery. The authors conclude inspiratory muscle fatigue following maximal exercise demonstrates that same pattern of recovery in both males and females. The authors could have used other measures to assess respiratory muscle fatigue such as FVC, FEV_1 and

PEF. It would have also been interesting to see if these pulmonary function measures would have trended the same as MIP.

Cordain et al. (1987) researched the effects of long-term exercise on respiratory muscle strength assessed by pulmonary function data in 101 male runners (at least one year and a frequency of three or more days per week) aged 16-58 years. Results revealed that runners exhibited significantly lower PE_{max} and significantly higher RV than the predicted values for height and age matched normal subjects. No other measure showed significance. The authors believe frequent consistent running may cause a non-pathological increase in RV due to reductions in expiratory muscle strength.

Bender and Martin (1984) hypothesized that the ability to ventilate maximally is decreased during and following exhaustive exercise. To evaluate this, they examined the measure of MVV (in 60-seconds) during the final minute and post-exhaustive treadmill exercise from 17 (14 male and 3 female) subjects (8 recreational athletes and 8 competitive runners). Each trial lasted for either three to ten-minutes or 60-minute duration of exhaustive exercise. Findings suggest the three to ten-minutes exercise duration failed to show any change in MVV. However, the 60-minute exercise showed significantly lower MVV values in the final minute and during the five and ten recovery intervals. The eight non-runners and the eight runners showed lower MVV values only at ten-minutes recover. The authors suggest the capacity to ventilate maximally declines only in long-term exhaustive exercise and the decline is most pronounced in non-runners.

Nourry et al. (2005) studied ventilation constraints in thirteen (nine males and four females) aerobically trained (TR) and eleven (seven males and four females) untrained (UT) prepubescent children by measuring the maximal flow-volume loop (MFVL) at rest and the

exercise flow-volume loops (EFVL) (plotted in the MFVL) during a progressive exercise test to exhaustion (8 to10-minute duration). The results show that TR had higher FVC and maximal expiratory flows than UT. In addition, TR reported higher VE, ERV/FVC and dyspnea associated with lower breathing reserve IRV/FVC and O_2 saturation values (SaO_2) at peak power as compared to UT. Authors concluded that because of their higher VE level, TR subjects present higher ventilatory constraints than UT.

The ability of the bronchial (intra-thoracic) airways to maintain patency, allowing for increases in flow rate during active expiration, is a major challenge of the respiratory system when the need for increased VE is required (often seen with intense exercise). This challenge in the bronchial airways with intense exercise occasionally presents a significant limitation to expiratory flow, thereby causing dynamic hyperinflation, increased respiratory muscle work, and VE limitation (Forster et al., 2012). Spirometry and other measures may be used to assess the airway before, during, and after exercise. Regardless of the techniques used to measure the ability to maintain airway patency, most research suggests that limitations exist when exercise duration and intensity are sufficient to create dynamic hyperinflation (caused by EFL) and/or respiratory muscle fatigue (also possibly caused by EFL) in both males and females equally (Ozkaplan et al., 2005). These limitations are supported by data by Cordain et al. (1987), suggesting frequent, consistent running may cause a non-pathological increase in RV (dynamic hyperinflation/EFL), and this increase may be caused by reductions in expiratory muscle strength (respiratory muscle fatigue). It is also notable that research measuring increases in ventilation in the absence of exercise as demonstrated in VIH trials suggests the exercise effects on pulmonary functions are independent of respiratory muscle work done (Coast et al., 1999). Lastly, when comparing these limitations on trained vs. untrained individuals, research suggests that because

of their higher VE level, trained subjects present higher ventilatory constraints than untrained subjects (Nourry, Deruelle, et al., 2005a).

1.4 Expiratory Flow Limitation

Exercise ventilatory limitation happens when the ventilatory output (VE) closely approaches or matches ventilatory capacity (Babb, 2013). EFL during exercise has been demonstrated in both males (Johnson, Saupe, & Dempsey, 1992) (Hue, Boussana, Le Gallais, & Prefaut, 2003) and females (McClaran et al., 1998). Currently, there is no agreed way to quantify ventilatory capacity, but some suggest the overlay of the exercise tidal flow-volume loop inside the maximal resting flow-volume loop (Babb, 2013). However, Babb (2013) points out that just making comparison of exercise tidal flow-volume loop with the maximal flow-volume loop measured at the mouth to view the scale of the EFL may not tell the whole story. Others suggest the use of FVC, FEV_1, PEF, FEF 50% and RV for a more effective ways of assessment (Beck, Hyatt, Mpougas, & Scanlon, 1999; Buono et al., 1981; Cordain, Glisan, Latin, Tucker, & Stager, 1987; Cordain et al., 1994). Regardless of the measure, approaching EFL may start a cascade of changes that could play an important role in creating ventilatory limitation during exercise and exercise intolerance (Babb, 2013).

The cause of significant EFL in many endurance athletes during heavy exercise is hyperinflation and an increase of their end-expiratory lung volume (Guenette, Witt, McKenzie, Road, & Sheel, 2007; Johnson et al., 1992; McClaran et al., 1998). Most of these athletes had normal airways and normal age-predicted maximal flow-volume data, but their high peak exercise capacities created extreme demand on ventilations and flow-rates, often resulting in EFL, hyperinflation, and reduced inspiratory capacities (Dempsey, McKenzie, Haverkamp, & Eldridge, 2008). Some of the complications with hyperinflation in the lungs are as follows: 1)

causes a reduction in dynamic lung compliance, increasing elastic work of breathing, thereby limiting the hyper-ventilatory response to heavy intense exercise, thus contributing to arterial hypoxemia and worsening dyspnea; 2) compromised cardiac output and stroke volume caused by increased afterload placed on the left ventricle by increased positive expiratory intra-pleural pressure with this pressure often exceeding the critical closing pressure of the airway; 3) a plateau of tidal volume at lower VE causing tachypnea; and 4) inspiratory muscle fatigue developing because of muscles functioning at shorter than their optimal length with a faster velocity of shorting operating at the limit of their dynamic capacity of their force generation (Babb, Viggiano, Hurley, Staats, & Rodarte, 1991; Dempsey et al., 2008; Guenette et al., 2007; Johnson et al., 1992; McClaran et al., 1998; Mota et al., 1999). EFL and this cascade of events outlined are more likely to occur in young females (because of smaller lungs) (McClaran et al., 1998) and older endurance athletes (loss of elastic recoil with normal aging) than young males (Guenette et al., 2007). The EFL in females can be explained largely by anatomical factors that affect the capacity to generate flow and volume during exercise as opposed to fitness related factors (Dominelli, Guenette, Wilkie, Foster, & Sheel, 2011). For a more complete review of the role and consequences of EFL during and after exercise, one should see the reviews in Babb (2013) and Dempsey et al. (2008).

Guenette et al. (2007) compared the mechanics of breathing (EFL, end-expiratory lung volume, end-inspiratory lung volume and the work of breathing) in endurance-trained athletes (eighth males and ten females) during cycling exercise. EFL measurement was derived from applying a negative expiratory pressure at the mouth as described in Mota et al. (1999). End-expiratory lung volume and end-inspiratory lung volume were achieved via inspiratory capacity maneuvers. Work of breathing was integrated by plotting the difference between esophageal and

airway opening pressure (trans-pulmonary pressure) against volume. The EFL limitation was seen in nine females and three males in the final stage of exercise. Women had higher relative end-expiratory lung volume, end-inspiratory lung volume, and work of breathing (two times) than males at maximal exercise. The authors believe that EFL, end-expiratory lung volume, and end-inspiratory lung volume may be more commonly experienced in females than in males at maximal exercise because of smaller lung volumes and airway diameter seen in females, leading to an increased work of breathing. These findings collectively suggest that females utilize a greater majority of their ventilatory reserve at a higher cost of breathing than males.

Bruno et al. (1981) set out to determine and track the effect of an acute exercise bout (continuous treadmill to exhaustion) on RV and TLC (determined by closed circuit O_2 dilution method) and other pulmonary functions measures over a 24-hour exercise recovery. They tested twelve males before and after exercise (5, 15, 30-minutes, 1, 2, and 24-hours). The results showed the RV significant increased by 20.8%, 16.8%, and 12.0% at 5, 15, 30 minutes of recovery from exercise, respectively. TLC showed significance increases at five (2.7%) and 15 (2.3%) minutes recovery. Interestingly, the FVC and FEV_1 were unchanged following exercise. It is possible the cool down protocol (3 miles per hour, 0% grade for 5 minutes) allowed these values to approach resting values and not show any significance. However, looking at the data (and something not mention by the authors), the FEF 25-75% measure (medium to small airways) showed an increase 5.8% at five and 7.6% 15 minutes recovery, respectively. Could this increase be reflective of a refractory period occurring? This was not an identified purpose of this study, but it should raise a reasonable question in the face of increasing RV and TLC if these increases reflect EFL.

Cordain et al. (1994) evaluated the mechanism that may be responsible for an often-observed acute increase in RV following exercise in 12 males that performed two exercise bouts on separate days. Subjects performed one exercise bout to maximal heart rate and one to 85% of maximal heart rate for 20-minutes. Pulmonary function measures were obtained prior to and at 5, 15, 30, 60, and 120-minutes post exercise. Results show significant increases in RV at 5, 15, and 30-minutes following maximal exercise and at 5 and 30-minutes after the submaximal exercise. Maximal exercise displayed a greater change in RV as seen in the submaximal exercise bout. Decreases were noted in PE_{max} and FVC, possibly caused by decreased expiratory muscle strength, but FEV_1 and FEF 75-85% were either unchanged or elevated. The authors addressed this by claiming, the increased FEV_1 and FEF 75-85% suggest there was little or no small airway compression by fluid volume shifts in the lung, as cited in their review of works. It is once again interesting to note this may be the result of refractory in the airways following exercise.

Babb et al. (1991) tried to determine the effect of mild-to-moderate airflow limitation on exercise tolerance and end-expiratory lung volumes by examining nine control subjects with normal pulmonary functions and twelve patients with mild-to-moderate air flow limitation during progressive cycle exercise. Data revealed that patients had a reduced (69% of predicted) VO2max as compared to controls (104% of predicted). End-expiratory lung volume was similar at rest in both groups (53% of TLC), but the maximal exercise values of patients decreased to 45% of TLC, and controls increased to 58% of TLC. The authors propose end-expiratory lung volume was significantly correlated to the FEV_1 and VO_{2max} values and this relationship suggests there is a ventilatory component to exercise capacity but that the increased end-expiratory lung volume could impinge on cardiovascular function during exercise. Within the discussion, the authors suggest the abnormal ventilatory response produced in the patients

because of their limited expiratory flow reserve values caused a reduction in their activities of daily living, thereby creating a deconditioned state. Interesting to note is that the normal controls also demonstrated some EFL at maximal exercise while still achieving their maximal predicted heart rate.

Hue et al. (2003) aimed to investigate pulmonary functions (ten-minutes before and ten-minutes after cycling trials) and compare them to those seen in the cycle/run succession as often performed by triathletes. Thirteen young males participated in three exercise trials: 1) 30-minutes of constant speed cycling followed by 20-minutes of constant speed running; 2) 30-minutes control constant speed cycling; and 3) 20-minutes of control constant speed running. The results for lung volumes and capacities for cycle-only trial showed significant increases in RV, FRC, and RV/TLC ratios, but there was no significance found in the pulmonary volumes or flows with the cycle/run or the run-only trials. Based on these findings the authors suggest cycling exercise by itself seems to increase post-exercise pulmonary volume changes that may lead to respiratory muscle (fatigue) alterations, and these changes may be a result of the crouched position of cycling. Other studies have suggested cycling induced a greater decrease in respiratory muscle endurance than running (Boussana et al., 2003; Boussana et al., 2001; Hill et al., 1991). Looking into the data more deeply, the FEF values showed slight increases for pre-values for the cycle/run and the run-only trials, which may suggest some airway refractoriness.

The series of events that are created by hyperinflation in the lungs can cause changes in dynamic lung compliance increasing the elastic work of breathing, compromising cardiac output and stroke volume, causing increased tachypnea, and inspiratory muscle fatigue, limiting dynamic capacity for force generation (Babb et al., 1991; Dempsey et al., 2008; Guenette & Sheel, 2007; Johnson et al., 1992; McClaran et al., 1998). Young females (because of smaller

lungs and airway diameter) and older endurance athletes (loss of elastic recoil with normal aging) experience higher incidences of EFL than young males. Females utilize a greater majority of their ventilatory reserve, thus significantly increasing their cost of breathing compared to males (Guenette et al., 2007). With concern to exercise modality, it seems cycling exercise by itself increases post-exercise pulmonary lung volume (increased RV) which may lead to respiratory muscle (fatigue) alterations, and these changes may be a result of the crouched position of cycling versus the upright position of running (Boussana et al., 2001; Hill et al., 1991; Hue et al., 2003). A study by Babb et al. (1991) suggested end-expiratory lung volume was significantly correlated to the FEV_1 and VO_{2max} values, thus a relationship of a ventilatory component to exercise capacity and an increase in end-expiratory lung volume could impinge on cardiovascular function during exercise. The author also suggested this might cause a deconditioned state (reduced activities of daily living) for individuals with an abnormal ventilatory response because of their limited expiratory flow reserve values. In this same study, the normal controls subjects also demonstrated some EFL at maximal exercise while still achieving their maximal predicted heart rate. Three of the five studies reviewed here, suggests a possibility of airway refractoriness seen in their subjects. Bruno et al. (1981) showed an increase in the FEF 25-75% measure at five (5.8%) and 15-minutes (7.6%) recovery, suggesting some increase in expiratory flow in the face of increasing RV and TLC values. Cordain et al. (1994) found elevation or no change in FEV_1 and FEF 75-85% suggesting little or no airway compression from fluid shifts in the lung. And lastly, a deeper review of Hue et al. (2003) of the individual data revealed slight increases in the FEF measures compared to pretrial data for cycle/run and run trials.

1.5 Exercise Induced Bronchoconstriction

Another area relevant to this review is exercise-induced bronchoconstriction (EIB). EIB is a transient narrowing of the lower airway during and after exercise in the presence or absence of clinically recognized asthma (Rundell, Spiering, Judelson, & Wilson, 2003; Weiler et al., 2010). EIB is the preferred term over exercise-induced asthma (EIA) because not all individuals with EIB have asthma. Also, in persons with asthma, exercise is not the inducer but the trigger for bronchoconstriction (Brown, Howard, Khan, & Carmody, 2012). The mechanism of EIB is based on two primary theories, the “osmotic theory” and the “thermal theory.” The osmotic theory suggests high ventilation rates during exercise causing excessive water loss for the airway surface liquid altering resident airway cell osmolality causing an inflammatory mediator release. The thermal theory states exercise causes airway cooling, and a rapid rewarming upon cessation of exercise leads to reactive hyperemia, edema, and obstruction (Rundell et al., 2003).

EIB is characterized as a ≥10 or ≥15 % of the reduction from pre to post exercise FEV_1 and is generally seen in three to fifteen minutes of recovery from exercise (Gotshall, 2002; Rundell et al., 2003). EIB is extremely common in persons with asthma (80-90%) and seen more frequently in individuals with more severe cases and in poorly controlled asthma as compared to only about 12-19% of the general population (Brown et al., 2012; Gotshall, 2002). About 40-50% of the individuals with asthma may exhibit a “refractory period,” (diminished bronchoconstriction to exercise if performed with 2-4 hours of first exercise) (Gotshall, 2002; Mahler, 1993; Randolph, 1997). The use of warm-up to induce a refractory period to limit the severity of EIB certainly can have merit for reducing symptoms, reducing the use of medications, and increasing exercise performance (Stickland, Rowe, Spooner, Vandermeer, & Dryden, 2012). EIB in elite athletes is generally higher than in the general population and varies based on the

type of sport, the maximum exercise level and certain environmental conditions (Brown et al., 2012). Khan (2012) displays the prevalence (percentage) of asthma occurrence in Olympic sports as cited in (Weiler, Layton, & Hunt, 1998; Weiler & Ryan, 2000) as follows: (60.7%) nordic-combined, cross-country, and short track; (50%) cycling and mountain biking; (29.6%) synchronized swimming and swimming; (24%) canoe/kayak, rowing and sailing/yachting, and alpine, long track, figure skating, snowboarding, and curling. These athletes indicated via a questionnaire, "They had been told either they had asthma" or "they had taken asthma medication at some time."

Rundell et al. (2003) set out to determine whether bronchoconstriction occurs during an interval-type simulated cross-country ski race and whether there is a period of refractoriness when a second bout of interval type exercise is initiated within 20-minutes post completion of the first session. They examined airway response and refractoriness during an approximate 42-minute cross-country ski time trial preceded by a six to nine-minute 2.5 km high intensity warm-up ski. Eighteen (thirteen males and five females) elite cross-country skiers completed seven successive 2.5km loops and had spirometry measured pre and at 5, 10 and 15-minutes post loop 1 and 20-seconds after loops 2-6 and then serially for up to 15-minutes after loop 7. Nine subjects demonstrated a ≥10% decrease from baseline in their FEV_1 (EIB+). Of the nine, five showed significant drops after loop 1, and the other four significantly dropped between loops 2-7 with one EIB+ subject showing significant refractoriness. The authors concluded EIB occurs in athletes during prolonged exercise with variable bronchial hyper-responsiveness onset that may influence performance. The lack of significant refractoriness in their cohort is consistent with an exercise bronchoconstrictive dysfunction and is different that asthma. This study's lack of

support for airway refractoriness may have been due to the limited time 15-minutes for recovery from exercise loop 1 to exercise loops 2-7 and the environmental exposure of the exercise.

The mechanism of EIB is in two primary theories, the osmotic theory (high VE rates cause water loss in the airway) and the thermal theory (airway cooling and rewarming lead to airway reactive hyperemia, edema, and obstruction). Either or both of these theories may contribute to EIB (narrowing of the lower airway during and after exercise in the presence or absence of clinically recognized asthma). The prevalence of EIB is common in 80-90% of asthmatics, 12-19% of the general population and in elite athletes with severity, depending varies based on the type of sport, the maximum exercise level, and certain environmental conditions can vary up 24-60%. It is also suggested about 40-50% of the individuals with asthma may exhibit a refractory period with a pre-exercise warm-up. In contrast, Rundell et al. (2003) suggest EIB occurs in athletes (different from seen in asthmatics) during prolonged exercise with variable bronchial hyper-responsiveness onset that may influence performance with only one of nine elite cross-country skiers displaying significant refractoriness. The lack of support for airway refractoriness may be influenced by limited time between the first trial (considered the warm-up exercise) and the successive trials (15-minutes) and/or the environmental exposure. EIB will be reviewed more fully in section III Respiratory System Warm-up.

1.6 Respiratory Muscle Training

Respiratory muscle training (RMT) can be divided into two distinctly different types, which are respiratory muscle strength training (resistive or threshold) and endurance (hyperpnea) training. These types have been used to improve the endurance performance of healthy, diseased, and athletic individuals (Beckerman, Magadle, Weiner, & Weiner, 2005; Enright & Unnithan, 2011; Griffiths & McConnell, 2007; Hanel & Secher, 1991; Hostettler et al., 2012; Leddy et al.,

2007; Sonetti, Wetter, Pegelow, & Dempsey, 2001; Uemura, Lundgren, Ray, & Pendergast, 2012; Weiner, Azgad, Ganam, & Weiner, 1992). Most studies on RMT propose an enhancement of endurance exercise performance in healthy and diseased individuals with less improvement seen in highly fit individuals. The most common types, respiratory muscle strength training and respiratory muscle endurance training, both have similar effect on performance improvements (Hostettler et al., 2012). Respiratory muscle strength training is divided into two types of either inspiratory and expiratory flow resistive-load or inspiratory and expiratory pressure threshold-load training (A. K. McConnell & Romer, 2004). In the inspiratory and expiratory flow resistive-load training model, individuals inspired or expired through a variable diameter orifice device, and the smaller the orifice size the greater the work required for any giving constant flow through the device. (Hostettler et al., 2012). In the inspiratory/expiratory pressure threshold-load training model, individuals created negative pressure by breathing through a device while trying to overcome a threshold-load set to initiate inspiration or expiration. Respiratory muscle endurance training, also known as Voluntary Isocapnic Hyperpnea (VIH), requires individuals to maintain high target levels of ventilation for a duration of up to 30-minutes (Coast et al., 1999; A. K. McConnell & Romer, 2004). The involvement of high levels of hyperventilation for prolonged periods with respiratory muscle endurance training makes the observed effect on the inspiratory or expiratory muscles impossible to separate (A. McConnell, 2009). The combined effect of inspiratory and expiratory muscle training is suggested to be superior in improving performance (Hostettler et al., 2012). When using inspiratory and expiratory muscle training, it is much easier to separate, thus giving a better indication of the role each muscle group has in performance outcomes (A. McConnell, 2009). A study to examine any crossover trial effect between inspiratory and expiratory muscle training found no significant effect of expiratory

muscle training on performance alone or coupled with inspiratory muscle training (Griffiths & McConnell, 2007). It is also suggested that adding expiratory muscle training to inspiratory muscle training during the same breath cycle may impair inspiratory muscle response to inspiratory muscle training (A. McConnell, 2009).

Non-traditional Training Programs- Beckerman et al. (2005) set out to assess the long-term effects of inspiratory muscle training on inspiratory muscle strength, exercise capacity, perception of dyspnea, quality of life, and utilization of medical care in patients with COPD. They evaluated 42 COPD patients with FEV_1 <50% of predicted (before and at 3, 6, 9, and 12 months during the training program) and randomly assigned them into either a training group (21 subjects) who did inspiratory muscle training for 1 year or a control group (21 subjects) who received training with very light load. The threshold intensity started at 15% of PI_{max} for the first week then progressed 5-10% daily until reaching 60%. This PI_{max} value was maintained from month one to month six of training. Subjects' parameters assessed were the FVC, FEV_1, six-minute walk test, PI_{max}, perception of dyspnea, and health-related quality of life. The data showed significant increases in inspiratory muscle strength (PI_{max}) by the end of the third month of training as well as an increase in the six-minute walk test. Significant improvement in quality of life was seen at the end of the sixth month, and a significant decrease in perception of dyspnea by the end of the ninth month was noted. All benefits were maintained throughout the 12-months, and a decrease in health care usage was noted. The authors believe the data suggest the long-term effect of inspiratory muscle training in COPD patients improved the measures of exercise capacity, quality of life, and perception of dyspnea, as well as reduced health care utilization. Other interesting observations were that none of the spirometry values significantly

changed over the duration of the study, and once a measure improved to a significant level, there was very little additional improvement seen from continued increases in training progression.

Weiner et al. (1992) examined adults with bronchial asthma by comparing specific inspiratory muscle training and sham training (placebo) in on inspiratory muscle strength/endurance, asthma symptoms, health care treatments for asthma, school or work missed days, and medication use (inhaled β2-agonist). Thirty individuals with moderate to severe asthma were divided into groups. One group of 15 individuals received the specific inspiratory muscle training, and the other 15 individuals were assigned the control sham training. Both groups trained five times a week for 30-minutes for six-month duration. The threshold intensity started at 15% of PI_{max} and progressed to 60% and then 80% for the last two months of training. Results show significant increases in inspiratory muscle strength as evaluated by PI_{max} at RV and significant increases in respiratory muscle endurance as expressed by the relationship between $P_{maxPeak}$ and PI_{max} in subjects in the specific inspiratory muscle-training group but not the sham-training group. The specific inspiratory muscle-training group showed significant improvements compared to the baseline data for asthma symptoms (nighttime asthma), morning tightness, daytime asthma, and cough, inhaled β2-agonist usage, number of health care days or visits, and amount of sick days missed due to asthma. The authors conclude a specific inspiratory muscle training program for six-months improves respiratory muscle strength and endurance, as well as in asthma related symptoms, health care usage, medication use, and loss work and school time. The spirometry data from before and after training showed small but significant increases in FVC and FEV_1 in the specific inspiratory muscle-training group as compared to the matched control (sham) group. Five individuals were able to stop taking oral/IM corticosteroid

medications during specific inspiratory muscle training group as compared to only one in the control sham group.

Hanel and Secher (1991) studied the effect of inspiratory muscle training for 10 minutes twice a day for 27.5 days on ten subjects in the training group (about 50% of PI_{max} intensity) and ten subjects in a sham-training group. They obtained data pre- and post-training on maximal oxygen uptake (VO_{2max}) maximal ventilations, maximal breathing frequency during exercise, run distance in 12-minutes on a track, resting PEF, FVC, FEV_1, PI_{max} and alveolar oxygen tension (pAO_2). Results from the inspiratory muscle-training group showed a significantly increased PI_{max}, a slight but significant decrease in breathing frequency. All the other measures derived from the inspiratory muscle-training group were similar to the control sham group. The author suggest inspiratory muscle-training results in significant increased PI_{max} but has no effect on VO_{2max}, run distance in 12-minutes, resting PEF, FVC, FEV_1, and alveolar oxygen tension (pAO_2). A possible limitation of this study was the training protocol parameters, which were twice a day for 10-minutes and a total of 27.5 days and about 50% of PI_{max} intensity as compared to the previously reviewed study by Weiner et al. (1992). In this study, authors trained their asthma patients five times a week for 30-minutes for a duration of six months at varying intensities of up to 80% of PI_{max}. Certainly, a comparison of a healthy subject's respiratory system to the respiratory system of an asthma patient's is not same, but an increase in the training protocol parameters (time, duration, and intensity) may have changed the results seen in Hanel and Secher (1991) study.

Griffiths and McConnell (2006) investigated the effect of four weeks of inspiratory muscle training and/or expiratory muscle training and the effect of a subsequent six-week trial of combined inspiratory and expiratory muscle training in club-level oarsmen on rowing

performance. They studied seventeen male rowers before and after training with ten performing inspiratory muscle training and seven performing expiratory muscle training. After the initial four-weeks of the two training protocols (about 50% of PI_{max}, and PE_{max} training intensity), all subjects performed six-weeks of combined inspiratory and expiratory muscle training. The measures evaluated at four and ten-weeks were PI_{max}, PE_{max}, minute ventilation, max flow volume loops (PIF, PEF, FVC, FEV_1 and FEF 50%) during an incremental rowing ergometer step test and a six-minute all-out (6MAO) effort. Results show significant increases in PI_{max} of 26%, an improvement in mean power during the (6MAO) of 2.7%, and a small decrease in heart rate up to about 5% in the inspiratory muscle-training group. The expiratory muscle-training group showed increased PE_{max} of 31% at the end of the intervention, but no other measure was significant during the step test or the 6MOA test. The authors believe inspiratory muscle training can improve rowing performance, but expiratory muscle training and a combination of inspiratory and expiratory muscle training did not produce any significant change in performance.

Enright and Unnithan (2011) evaluated the effect of inspiratory muscle training at varying intensities on inspiratory muscle function, VC, TLC, work capacity, and power output in forty healthy individuals. Subjects were randomly assigned to four groups. One group was assigned to be control with no training. The other three groups completed an eight-week inspiratory muscle-training program set at either 40, 60, or 80% of sustained PI_{max}. Training was done three days a week, with 24 hours separating training days. Before and after training measures of body composition, VC, TLC, MIP, sustained MIP, work capacity and power output were obtained. The results show significant increases in MIP and SMIP at all intensities (40, 60, and 80%), whereas the 60 and 80% training intensities demonstrated increased significance in

work capacity and power output. The 80% training intensity was the only group to show significant improvements in VC and TLC. The authors believe if substantial pressures are generated during a program of high intensity inspiratory muscle training then significant improvements in lung volumes, work capacity, and power output may be seen in healthy subjects.

Uemura et al. (2012) compared two different types of respiratory muscle training on the exercise performance of eight (four males and four females) experienced runners. The training consisted of a four-week, twelve-session resistive respiratory muscle training (60% of PI_{max}, and PE_{max} intensity). Followed by a four-week, twelve-session VIH training (40% of the MVV/ breathing frequency) with the measures of spirometry (FVC, SVC, FEV_1, MVV PI_{max}, PE_{max},), respiratory endurance time, VO_{2max}, running time to voluntary exhaustion at 80% of VO_{2max}, blood lactate concentration, and minute ventilation obtained before and about five days after each training protocol. Pre- and post-training changes were seen with resistive respiratory muscle training improved inspiratory muscle strength significantly by 23.8% and 18.7% at rest and post exercise run test, respectively. VIH training significantly increased respiratory endurance time to exhaustion by 237.8%, SVC by 3.43 %, and decreased MVV by 20%. Both respiratory training protocols significantly increased the duration of the endurance run by 17.7% for the resistive respiratory muscle training and 45.5% for the VIH training. No other measures showed significant change in either of the respiratory training protocols. Interesting to note was after VIH training, FVC and FEV_1 did show slight increases, though not viewed as significant by the authors. Also important to consider is comparing the two training protocols, VIH followed inspiratory/expiratory muscle training, which may have an augmenting effect on the VIH results.

Leddy et al. (2007) examined the effect of VIH training with the intensity set at about 50% of VC and MVV values for four-weeks and 30-minutes a day on the respiratory system and running performance in twenty-two male competitive runners (fifteen in the training group and seven in the control sham group). The measures assessed were FVC, FEV_1, MVV, MIP, MEP, VO_{2max}, four mile run-time, treadmill run-time to exhaustion at 80% of VO_{2max}, serum lactate, total ventilation, VO_2, oxygen saturation, and cardiac output before and after the four-weeks (post one day and post seven days) day of training. Spirometry data and four-mile run time measured every month during the three-month maintenance period. The data show significant improvements seven days post training in MVV (+10%), respiratory endurance (+208%), treadmill run-time (+50%), along with reductions in four-mile run time (-4%), respiratory breathing frequency (-6%), VE (-7%), VO_{2max} (-6%), lactate (18%), during the treadmill run test. Of these, the four-mile run time remained above pre-training levels for the three months maintenance period where reduced VIH training was noted. The authors believe seven days of rest following an intense four-week, VIH training program is important to reveal the ergogenic effect gained by training and that the gain can be maintained during a subsequent period of reduction in VIH training frequency.

Beckerman et al. (2005) and Weiner et al. (1992) researched the effect of inspiratory muscle training on individuals with airway disease (COPD and Asthmatics) and found improvements in exercise capacity, quality of life, asthma related symptoms, loss work and school time, and perception of dyspnea, as well as reduced health care/medication utilization. Four studies examined the effects of inspiratory or expiratory muscle training protocols. Hanel and Secher (1991) showed significance only in PI_{max}, but used a limited protocol in time, duration, and intensity. In contrast, the remaining authors that utilized inspiratory muscle training

protocols found significance in multiple measures, including increases in performance. Griffiths and McConnell (2006) used six weeks of RMT training at 50% of PI_{max} and PE_{max}, and found inspiratory muscle training superior to expiratory muscle training in improving mean power (2.7%) in a six-minute all-out rowing effort. Enright and Unnithan (2011) found performance improvements (work capacity and power output) in their subjects at 60 and 80% of PI_{max} training intensity and three days a week for eight-weeks. Uemura et al. (2012) studied both inspiratory/expiratory muscle training and VIH and found the VIH training to be superior in enhancing performance (endurance run) over inspiratory/expiratory muscle training (45.5% and 17.7%, respectively), but both show increases. However, it should be noted that the four weeks of VIH training followed the four-week inspiratory/expiratory muscle training, thus creating an additive effect on the VIH results. Leddy et al. (2007) also examined an VIH training protocol on running performance and found that treadmill run-time increased at day one post training (29%) and seven days post-training (50%) in four-weeks of training for 30-minutes a day. Some studies showed significance in pulmonary function measure with inspiratory muscle training improvements in FVC and FEV_1 (Weiner et al., 1992) and VC and TLC at 80% intensity training (Enright & Unnithan, 2011). Because of the nature of each training protocol, the inspiratory or expiratory muscle training displayed significant improvements in PI_{max} and PE_{max}, respectively (Griffiths & McConnell, 2007; Hanel & Secher, 1991; Uemura et al., 2012; Weiner et al., 1992), and the VIH showed significance improvements in MVV (Leddy et al., 2007; Uemura et al., 2012).

Traditional Training Programs- The beneficial effects of exercise are often seen in many body systems with any type of exercise if performed on a consistent basis, across the life span of all individuals. Exercise training can delay many pulmonary changes seen with ageing and

reduce other related risk factors to chronic lung disease, though many studies have been inconsistent on the influence of exercise on pulmonary function (Huang & Osness, 2005). Swimming and running are just two examples of aerobic exercise that can be considered the best for maintaining health and physical fitness and are known to have a profound effect on lung function for many individuals (Sable, Vaidya, & Sable, 2012). Research on the effect of resistance training on pulmonary functions (Singh, Jani, John, Singh, & Joseley, 2011) is rare at best, but the latest pulmonary rehabilitation guidelines recommend upper extremity resistance training in COPD patients for improved reconditioning programs (Ries et al., 2007). The following is a review of studies on the influence of general aerobic conditioning programs (Sable et al., 2012; Shinde et al., 2013), the impact of high-intensity interval aerobic conditioning programs on pulmonary functions (Dunham & Harms, 2012; Nourry, Deruelle, Guinhouya, et al., 2005) and resistance training (Singh et al., 2011).

Sable et al. (2012) examined the pulmonary functions of two different groups of athletes, swimmers and runners to make comparisons on lung function. Thirty swimmers who trained at least two to three kilometers per day regularly were compared to a matched group of thirty middle distance runners. Both groups trained for the previous three years. The measures of tidal volume, FVC, FEV_1, and MVV were significantly higher in the swimming group than in the running group. The authors believe the effect of swimming exercise influences lung volume measurements because the respiratory muscles of swimmers are required to develop greater pressure as a consequence of immersion in water during the respiratory cycle, leading to functional improvements of the muscles (like the diaphragm) involved in breathing. This study shed some light on the value of training the respiratory muscles through exercise as these individuals trained for the last three years. It would be interesting to know the percentage

predicted values for each of the groups studied and how a control group of non-exercisers would have changed the results.

Shinde et al. (2013) examined the effect of aerobic exercise training and yoga exercise on weight reduction and pulmonary functions before and after exercise training (one-year). Sixty male and female subjects (30-50 years) with diagnosed obesity (grade I or II as calculated via BMI) were divided into two matched groups randomly. One group was the aerobic exercise training group (walking, 45 to 60-minutes a day for five days a week) and the other as the yoga exercise group (various yoga exercises, 45 to 60-minutes a day for five days a week). At the one-year follow-up, the results showed significance improvements in the measures of BMI, FVC, FEV_1/FVC, and MVV in the yoga group as compared to the aerobic training group. The authors conclude regular practice of yoga is beneficial in weight reduction and improves pulmonary functions. Certainly, one can view this research as very interesting, but the important variable to keep in mind is that yoga emphasizes that use of breathing control and techniques done in various postures/poses, which, in turn, may improve pulmonary function. In addition, the aerobic exercise training group protocol did not control for exercise intensity, possibly the cause of limited improvement.

Dunham and Harms (2012) set out to determine whether high-intensity interval training (HIT) would increase respiratory muscle strength and expiratory flow rates more than aerobic endurance training (ET) alone. Fifteen physically active healthy subjects were divided randomly into either a high-intensity interval-training group (eight subjects) or an aerobic endurance-training group (seven subjects). The high-intensity interval-training group completed a four-week training program of three days a week, exercising on a cycle ergometer at 90% of VO_{2max} in intervals of one minute 90% work rate, then a three minute at 20-watts, and repeated the

interval for a total of 20-minutes. The endurance-training group completed the same four-weeks of training, the same three days a week, but trained for 45-minutes at 60-70% of VO_{2max} of constant load cycling. Of the values assessed before, at two-weeks of training, and after the completed training program, both groups showed significant improvements in VO_{2max} (about 8-10%), five mile time trial (6.5%) HIT and (4.4%) ET. Both groups significantly increased PI_{max} post training (43%) HIT and (25%) ET. The HIT group had significantly higher measures than the ET group. No changes were noted in the expiratory flow rates in either training group. The authors believe both whole-body aerobic endurance exercise training and high-intensity interval training are effective in increasing inspiratory muscle strength, with HIT offering a more time-efficient method than ET in improving aerobic capacity and performance. It is reasonable to believe that the duration of the program (four-weeks) was the reason the training programs did not have more of an effect to the pulmonary function values, but it should be noted that a closer look at the PEF measure also demonstrated improvements (28% for HIT and 9% for ET) with both training groups from pre-training values.

Nourry et al. (2005) investigated the effect of intermittent, short-duration, high-intensity running training on resting and exercise pulmonary function in healthy, pre-pubescent children. The training group consisted of three females and six males (age 9.7 years). They participated in eight-weeks of high-intensity intermittent run training and compared to a control (regular physical activities) group of four females and five males (age 10.3 years). The training group performed their regular physical education in school and trained two additional days at a percentage of their maximal aerobic speed (MAS, determined via a 20m shuttle run test). The training sessions (about 30 minutes of total exercise) consisted of a warm-up of ten second runs at 100% of MAS followed by a series of varying, four short, intermittent exercise runs (10-20

seconds runs at 100-130% range of MAS) separated by three minutes of passive recovery. After the eight-week training program, no change was seen in the control group, but the training group significantly increased FVC (7%), FEV_1 (11%), PEF (17%), FEF 50% (16%), FEF 75% (15%), as well as, VO2max (15%), VE (16%), VT (15%). The author suggests eight-weeks of high-intensity intermittent run training can improve resting pulmonary function and exercise ventilation in prepubescent children.

Singh et al. (2011) examined the effect of upper-body resistance training on pulmonary function in 30 male smokers (age 25-55 year). The subjects were randomly assigned to two groups. One been an exercise group of fifteen subjects (experimental group, EG) and a second non-exercise control group fifteen subjects (CG). The EG exercised for four-weeks, three times a week on non-consecutive days, using upper-body resistance training (five major muscle groups, 50-85% of the one rep maximum, three sets of ten repetitions) and conventional deep breathing exercises. The CG only did conventional deep-breathing exercises and remained inactive otherwise. Pulmonary function assessed before and after 4 weeks of training revealed significant improvements FEV_1 (9%) and FEV_1/FVC (9%), but no change in FVC. The CG groups had no significant changes noted, and removing any direct effect of the conventional deep breathing exercises may have contributed to the improvements in pulmonary measures. The authors concluded that four-weeks of upper-body resistance training program produced significant changes in pulmonary functions in male sedentary smokers.

Sable et al. (2012) examined the pulmonary functions of two different groups of athletes, swimmers and runners, and found swimmers displayed significantly higher pulmonary function values than runners, the nature of which may be explained by the swimmers’ exposure to water immersion increasing the pressure the respiratory muscles work against during their aerobic

training. Shinde et al. (2012) found the regular practice of yoga (> one year) as compared to aerobic training is beneficial in weight reduction and improves pulmonary functions, which can be attributed to use of breathing control, and techniques are done in various postures/poses emphasized in yoga training. It is important to note that in the aerobic training group, the training protocol did not control for intensity, thus limiting the results of this group. Dunham and Harms (2012) used two training protocols (aerobic training and HIT) and found significant improvements in performance (VO_{2max} and time trials), as well as PI_{max}, and PEF with both training protocols, but the HIT group proved to be superior. Nourry et al. (2005) also investigated an eight-week HIT program with significant improvements in performance (VO_{2max}) and pulmonary functions measures. Lastly, a study Singh et al. (2011) used upper body resistance training to show improvements is pulmonary function measures in just four-weeks. As shown here, regardless of the training traditional aerobic, yoga, HIT, or upper body resistance training result in positive effects pulmonary function and enhanced performance. Something interesting to note, is that of the protocols review here, the ones that challenged the respiratory system (with high ventilation requirements or respiratory muscle work) produced the most improvement.

1.7 Respiratory System Warm-up

This section will review that relevant research done on ways to use pre-exercise warm-up to limit any EIB seen in individuals that may be prone to airway narrowing and any effects on exercise performance. As discuss earlier, a refractory period may develop after specific warm-up protocols, thus creating a period in which further vigorous exercise results in significantly less severe or no EIB (Stickland et al., 2012). Refractory period may occur in about 40-50% of the individuals that have an initial episode of EIB but then experience a diminished responsiveness

that can last from 1-4 hours after the initial warm-up exercise (Randolph, 1997). The mechanism leading to a refractory period is unclear, but some suggest it may be mediated by a depletion of catecholamine, an increase in circulation of prostaglandin, a degranulation of mast cells mediators (Anderson & Holzer, 2000), or by an increase in bronchial blood flow and in the rate of water return to the airway surface (Kippelen et al., 2012). The thought of a mechanism to consistently create a refractory period in individuals with EIB or non-EIB individuals that perform heavy intensity exercise that may be prone to EFL is very appealing because it could promote fewer symptoms, decreased medication use, and improved exercise performance (Stickland et al., 2012).

Research on the effects of pre-exercise warm-up can be divided into three areas based on the type of warm-up protocol studied (interval, continuous high intensity, and continuous low intensity). Some studies examined multiple types of warm-up strategies/protocols. Of the interval type protocols, four studies will be reviewed (de Bisschop, Guenard, Desnot, & Vergeret, 1999; McKenzie, McLuckie, & Stirling, 1994; Mickleborough, Lindley, & Turner, 2007; Zach, Schnall, & Landau, 1980); for the continuous high-intensity protocols, two studies will be reviewed (Reiff, Choudry, Pride, & Ind, 1989; Zach et al., 1980); and for the continuous low-intensity protocols, three studies with be reviewed (McKenzie et al., 1994; Morton, Fitch, & Davis, 1979; Reiff et al., 1989).

The interval warm-up protocols involve repetitive sprints of 20-30 second duration at 100%+ of maximal effort (VO_{2max} or higher) as a warm-up before an exercise challenge. Results are compared to the same exercise challenge with no pre-challenge warm-up acting as the control for the studies. The recovery time assessment of pulmonary function measures after the exercise challenge varies up to ten minutes to intervals of 15, 25, and 80 minutes.

Research by de Bisschop et al. (1999) examined the effect of a warm-up protocol on exercise-induced asthma in asthmatic children to allow them participate more fully in activities that induce their asthma. In the first study, measurements of peak flows were assessed before, during, and after (5 and 10 minute) a seven minute run (EX1) outdoors on a track in 16 asthmatic children (mean 11 years). Then three pre-EX2 warm-up schedules were used of varying intensity/speed (SRWU 1=100%, SRWU 2=120%, and SRWU 3=130%) on different days. These SRWU consisted of a series of five short runs at a speed/intensity percentage of EX1 and 7.5% of the EX1 (distance achieved) with 1.5 minutes between runs and 5 minutes between two series of runs and 10 minute recovery before EX2. In the second study, 30 young asthmatic children (mean 12 years) performed a seven-minute run alone (EX1) or the same run (EX2) after the SRWU2 schedule. In all trials, medication was withheld for 12 hours prior to testing. The results showed that in 24 of 30 children, the fall in PEF after EX2 was significantly less than the fall after EX1. The percentage fall in PEF after EX2 was significantly correlated to the same changed induced by the SRWU2 protocol. From the SRWU2 protocol, the children were divided into three sub groups: G1) increased PEF, 10 or 30 subjects, G2), 15% fall in PEF, 14 of 30 subjects, (G3). Fifteen percent fall in PEF 6 of 30 subjects. The G3 subgroups had no significant change with the application of SRWU2 to EX2 recovery compared to EX1 recovery. The authors believe the change in PEF after a SRWU period was a good predictor of the occurrence of bronchoconstriction after EX2. Thus, a SRWU can reduce the decrease in PEF for most of the children (24 or 30 subjects) in this study, thereby reducing subsequent post-exercise bronchoconstriction. Subjects in G1 and G2 sub-groups also improved their distance by 5% from EX1 to EX2, suggesting an enhancement in performance.

Mickleborough et al. (2007) investigated the efficacy of a high-intensity interval warm-up protocol and compared it to medication dosing with salbutamol (commonly used β2- agonist for prevention or relief of asthma symptoms) on the severity of EIB and whether a combination of medication and a warm-up protocol provide greater protection against EIB that either intervention alone. Eight moderately-trained recreational athletes with documented EIB were tested in four experimental conditions: 1) control (CON); 2) an interval warm-up (WU) consisting of 8x30 second runs at peak treadmill speed, with 45 seconds recovery between each run; 3) inhaling 200µg of salbutamol (IH); and 4) combining both WU and IH treatments. The four interventions were followed 15 minutes rest and then subjects performed an exercise challenge test (85-90% of predicted maximal heart rate for eight minutes). Pulmonary functions were measured before and after (1, 5, 10, 15 minutes recovery). Results reveled that in the CON intervention the pre-to-post exercise mean drop FEV_1 in all eight subjects was -18.25%. The mean decrease for the WU interventions post-exercise FEV_1 significantly reduced to only -9.1% (falls below the diagnostic threshold of 10% decrease in FEV_1 post-exercise). The IH and WU+IH interventions produced significant bronchodilation with mean maximum percentage change of post-exercise FEV_1 following the IH was an increase of +8.9% and WU+IH +15.2%. The FEF 25-75% also showed similar significance. The authors believe the data indicate that repeated high intensity warm-up can lessen the EIB and that combining the WU and IH interventions resulted in a substantial bronchodilation adding a protective effect against the development of EIB as compared to the interventions alone.

McKensie et al. (1994) examined the protective effects of continuous low-intensity warm-up and an interval warm-up exercise on post-exercise bronchoconstriction in athletes with exercise-induced asthma. Twelve moderately trained subjects with asthma were tested under

three experimental conditions: 1) continuous warm-up (CW); 2) interval warm-up (IW); 3) control (C). The CW intervention group performed 15 minutes of treadmill running at a velocity of 60% of VO_{2max} followed by two minute rest and then an exercise challenge test (ET=6 minutes at 90% VO_{2max}). The IW intervention group preformed 8x30 second runs (1.5-minute rest between each run) at intensity of 100% VO_{2max}, followed by two-minute rest and then the same ET. The C group only performed the ET. The measures of FVC, FEV_1 and mean maximum PEF (MMPEF) were assessed (expressed as the percent change in baseline values) at rest before any exercise condition and every 2 minutes during a 25 minute passive recovery period. The results show significant difference in FEV_1, FVC, and MMPEF for the CW (16.7, 10.7, and 30.2 %, respectively) over the IW (29.7, 21.0, and 43.4 %, respectively) or the C (34.6, 30.0, and 50.0%, respectively). The author suggests a CW exercise of 15 minutes at 60% of VO_{2max} can significantly reduce post-exercise bronchoconstriction in moderately trained athletes with asthma. The results suggest the CW protocol was significantly better than an IW protocol, but the IW was still significantly better than the control. One could view the short rest period (2 minutes) between pre-exercise warm-ups as a limitation of this study possibly leading to the limited results for interval warm-up as compared to the continuous warm-up.

Schnall et al. (1980) examined the notion of bronchodilation produced by short periods of running in subjects in which EIB had occurred after a standard exercise test. Eight subjects (12-31 years) with a previous history of EIB (free of symptoms of asthma who had received no medication with in the last eight hour before testing) were tested on separate days with three test trials. The trials were as follows: 1) running twice (run A and run B) on a treadmill (10% grade and speed to produce a heart rate of 180b/m) for six-minutes each with a 49-minute break between each run (control); 2) performed a six-minute running (run C) followed by ten-minute

rest then seven short runs (120-130% of the six-minute run) of 30 seconds each with rest periods of 2.5 minutes between each short runs and then 20 minutes rest followed by a second period of running for six-minutes (run D); and 3) performed seven-minutes of short runs was completed 20 minute before the six-minutes of running (run E). The data shows significant change in the mean maximal post-exercise falls from baseline (resting) for the PEF, FEV_1, and FEF25-75% measures comparing run A (control) 22.8, 23.0, and 37.3%, respectively, to run E (run following short runs only) 10.4, 6.9, and 18.9%, respectively. The values (FEV_1 and PEF) for run D revealed significantly less fall in the mean maximal post-exercise change in values that run A. The authors suggest repeated, short runs minimize the bronchoconstricting effect on subsequent exercise stress and have a bronchodilating effect on previous EIB. They also suggests the data provide evidence to support that asthmatics cope better with repeated, short duration activities and that warm-up period may be beneficial in alleviating the effects of more prolonged exercise.

The four studies outlined above using an interval protocol involved 52 subjects. The protocols compared the percentage fall in FEV_1 and/or PEF on an exercise trial with and without (control) an interval warm-up before. Spirometry measures after exercise trials were collected at varying times (up 10, 15, 25, 80 minutes). The interval warm-up protocols consisted of repetitive sprints of 26-30 seconds at maximal intensities (≥100% VO_{2max}). The mean difference in the maximal percent fall in FEV_1 and PEF from the control exercise trial as compared to the exercise warm-up trial, ranged from about 4.9-16.1% and 11.6-30%, respectively. The data supports significant difference from control to interval warm-up protocols and a general benefit of these types of protocols. The recovery times between warm-ups and exercise test varied from 2 minutes up to 20 minutes. Two studies reported a performance measure (distance or VO_{2max}) during their studies; with de Bisschop et al. (1999) suggesting a 5% improvement in distance

cover on a track with interval warm-up and Mickleborough et al. (2007) reported no significant improvement in VO_{2max} with interval warm-up alone.

Continuous high-intensity protocols involve continuous high-intensity warm-up with a control exercise challenge with no warm-up. The warm-up exercise intensity was on the high end of VO_{2max} (heart rate of 180 or 98% of max predicted) with the recovery pulmonary function assessment measured up to 80-90 minutes after the exercise challenge.

Reiff et al. (1989) examined the effect of a prolonged warm-up period of exercise on subjects with EIA. Seventeen asthmatic subjects with known EIA were tested using two different randomized exercise protocols: 1) a 6-minute treadmill trial at 6 kph and 15% grade (S1A, producing 98% of max predicted heart rate): (continuous high-intensity) followed by the same exercise trial (S2A) with 45-minutes rest between (day A); 2) a 30-minute treadmill at 6 kph and 3% grade (W1B) with 21-minutes rest (continuous low-intensity warm-up) followed by the same exercise test trial (S2B) used in day A (day B). The mean maximal percent fall in FEV_1 and PEF from base line are as follows: S1A= 46% and 51%, respectively; S2A= 29% and 32%, respectively; W1B= 17 % and 21%, respectively; S2B= 26% and 27%, respectively. The data supporting refractoriness was demonstrated on the S2A compared to the S1A and that W1B produced significantly less EIA than S1A with significant refractoriness to bronchoconstriction after the S2B. The authors conclude a warm-up period of exercise can induce refractoriness to EIA without itself producing marked bronchoconstriction.

Schnall et al. (1980), as review earlier, examined continuous high-intensity protocol vs. interval warm-up protocols. The continuous high-intensity had subjects running twice (run A and run B) on a treadmill (10% grade and speed to produce a heart rate of 180b/m) for six- minutes each with a 49-minute rest between each run. The data suggest the interval warm-up protocol

was superior to continuous high-intensity protocol and had more significant change in the mean maximal post-exercise falls from baseline (resting) than the use of run A (continuous high-intensity warm-up) and then run B.

Continuous high-intensity protocols involve 25 subjects. The mean difference in fall from baseline for FEV_1 and PEF ranged from 6.9-17% and 10.4-21%, respectively. The data supports significant difference from control to continuous high-intensity protocols and suggests some benefit of these types of protocols. The recovery times between warm-ups and exercise test were from 20 or 49-minutes. None of the studies reported measures of performance.

Continuous low-intensity warm-up protocols use a warm-up exercise for duration of three to 30 minute with an identical control challenge with no prior warm-up. The intensity for these warm-up protocols used 60% of HR_{max}, 60% VO_{2max}, or just a low intensity warm-up (30-minute treadmill at 6 kph and 3% grade). The recovery pulmonary function assessments were measured at up to 25, 30, and 90 minutes after the exercise challenge.

Morton et al. (1979) set out to determine the effect of warm-up on EIA. Eighteen subjects (ten males and eight females) performed two trials of a five-minute sub-maximal treadmill running to reach a heart rate of 85% of predicted maximum for age with one preceded by a warm-up and one not preceded by a warm-up (control). The warm-up protocol involved walking or jogging on a treadmill for three minutes to produce 60% of the subject’s maximum predicted heart rate with less than a minute between completions of warm-up to the exercise test. The results showed the mean maximal percentage fall in FEV_1 displayed no significant difference from the two intervention trials (control and warm-up trials). The authors concede while their study does not support the concept of warm-up to reduce the likelihood of EIA, the

recommendation of a longer, more intense warm-up involving interval activities should be considered with future studies.

McKensie et al. (1994) as reviewed earlier compared a continuous warm-up (CW) and interval warm-up (IW) exercise on post-exercise bronchoconstriction in athletes with exercise-induced asthma (EIA). The subjects were tested under a CW protocol performing 15 minutes of treadmill running at a velocity of 60% of VO_{2max} followed by two-minute rest and then an exercise challenge test (ET=6 minutes at 90% VO_{2max}). The results suggest the CW protocol was significantly better than an IW protocol but the IW was still significantly better than the control.

Reiff et al. (1989) as reviewed earlier, compared a continuous high-intensity warm-up and a continuous low-intensity warm-up on subjects with EIA. The subjects were tested with a continuous low-intensity warm-up protocol and performed a 30-minute treadmill at 6 kph and 3% grade warm-up with 21-minutes rest followed by the exercise test trial. The data suggest the continuous low-intensity warm-up protocol produced significantly less EIA than the other continuous high-intensity protocol.

The three studies using continuous low-intensity protocols involve 47 subjects. The mean difference in fall from baseline for FEV_1 and PEF ranged from 16.7-29% and 30.2.-32%, respectively. One study showed no significance in either measure (Morton et al., 1979). Most of the data supports slight significant difference from control to continuous low-intensity protocols and suggests some limited benefit of these types of protocols. The recovery times between warm-ups and exercise test were from zero, 2, or 45-minutes. The zero-minute rest between warm-up and exercise test protocol was also the study that showed no significance with a continuous low-intensity. None of these studies reported measures of performance. Table1.1 summarizes these studies.

1.8 Implications for Future Research

Many physiological mechanisms have been proposed concerning why exercise may cause airway refractoriness. The effect of exercise on the airway may result in dehydration of the airway surface, leading to an increase in airway osmolarity. This increased osmolarity creates inflammation, thereby releasing mediators of prostaglandins, leukotrienes, and histamine from mast cells causing bronchoconstriction (Anderson & Holzer, 2000). Anderson and Holzer (2000) noted that the mechanism of EIB in asthmatics may be of a different pathophysiological mechanism than that of EIB in athletes. The causes of airway refractoriness are unclear, but it is suggested that a depletion of catecholamines, an increased circulation of prostaglandin, or degranulation of mast cells mediators are possible reasons. Regardless of the reasons, several researchers have tried to develop studies that create refractoriness, thus improving pulmonary functions in asthmatics and athletes alike. The thought of a mechanism to consistently create a refractory period in individuals with EIB or non-EIB individuals that perform heavy intensity exercise that may be prone to EFL is very appealing because it could promote fewer symptoms, decreased medication use, and improved exercise performance (Stickland et al., 2012).

When examining the current and relevant research, one realizes that no single warm-up protocol was consistently used in multiple studies. Though similar protocols may be grouped into general categories, such as interval, continuous high-intensity, and continuous low-intensity, there seems to be no agreement on the exact method to recommend. All the protocols reviewed use a traditional training program (aerobic based or HIT based) for the basis of their warm-up program. Five of the six studies that reviewed specific to warm-up protocols found significance in pulmonary function measures as compared to controls. The one study (Morton et al., 1979) with no significance in pulmonary function measures used a warm-up protocol that had no rest

Table 1.1 Summary of warm-up protocols.

Study	Year	Protocol type(s)	Subjects/ Controls	Definition of EIB % fall in FEV1	PFT	Warm-up (WU) protocol	Duration WU and ET (minutes)	Exercise Test, Time, Type, Intensity	% change of resting FEV1 and/or (PEF)
de Bisschop	1999	Interval	36 (11-12 years), same subjects	≥15% FEV1	PEF	5 short runs at a speed/intensity percentage of EX1 (100, 120, or 130 %) and 7.5% of the EX1 (distance achieved) with 1.5-minutes between runs and 5-minutes between 2 series of runs	10	7m track@ max effort	(26.8% over controls of 37.9% avg. for 3 groups)
McKenzie	1994	Interval & Continuous Low-Intensity	12 (26.5 years), same subjects	≥15% FEV1	FEV1	(continuous low-intensity) CW performed 15-minutes of treadmill running at a velocity of 60% of VO_{2max} followed by two-minute rest and then an exercise challenge test (ET=6 minutes at 90% VO_{2max}). (Interval) IW preformed 8x30 second runs (1.5-minute rest between each run) at intensity of 100% VO_{2max}, followed by two minute rest and then the same ET.	2	6m TM @ 90% VO_{2max}	CW=16.7%, IW=29.7%, and C=34.6% (CW=30.2%, IW=43.4%, and C=50%)
Mickleborough	2007	Interval	8 (19.5 years), same subjects	≥10% FEV1	FEV1, FVC, FEF 25-75%	(Interval) warm-up (WU) consisting of 8x30 seconds runs at peak treadmill speed, with 45-seconds recovery between each run	15	8m TM@ 85-90% MPHR	9.1% over controls of 18.25%

(Table 1.1 continued)

Schnall	1980	Interval & Continuous Hi-Intensity	6 (12-31 years), same subjects	NR	PEF, FEV1, FEF 25-75%	(control) & (continuous high-intensity) running twice (run A and run B) on a treadmill (10% grade and speed to produce a heart rate of 180b/m) for six-minutes each with a 49-minute break between each run (Interval mixed) IM performed a six-minute running (run C) followed by ten minute rest then seven short runs (120-130% of the six minute run) of 30 second each with rest periods of 2.5 minutes between each short runs and then 20-minutes rest followed by a second period of running for six-minutes (run D) (Interval) performed seven-minutes of short runs was completed 20-minute before the six-minutes of running (run E).	49, 20	6m TM@ 10% incl. HR=180	I=6.9% over controls of 23.0% (I=10.4% over 22.8%) IM=16% (14%)
Reiff	1989	Continuous Hi-Intensity & Continuous Low-Intensity	17 (16-32 years), same subjects	≥15% FEV1	PEF, FEV1	(control) & (continuous high-intensity) a 6-minute treadmill trial at 6 kph and 15% grade (S1A, producing 98% of max predicted heart rate) followed by the same exercise trial (S2A) with 45-minutes rest between (day A) (continuous low-intensity) a 30-minute treadmill at 6 kph and 3% grade (W1B) with 21-minutes rest then followed by the same exercise test trial (S2B) used in day A (day B).	45, 21	6m TM@ 15% incl. & 6km*h 97% MPHR	CL=17% over controls of 46% 21% over 51%) CH=29% (32%)

(Table 1.1 continued)

Morton	1979	Continuous Low-Intensity	18 (11-33 years), same subjects	≥15% FEV1	FEV1	a five-minute sub-maximal treadmill running to reach a heart rate of 85% of predicted maximum for age with one preceded by a warm-up and one was not (control). The warm-up protocol was walking or jogging on a treadmill for three minutes to produce 60% of the subject's maximum predicted heart rate with less than a minute between completions of warm-up to the exercise test.	<1	5m TM @ 85% MPHR	No significance

interval between warm-up exercise and the exercise test and possibly lead to the lack of airway refractory observed. The one study (Morton et al., 1979) with no significance in pulmonary function measures used a warm-up protocol that had no rest interval between warm-up exercise and the exercise test and possibly lead to the lack of airway refractory observed. When considering the effect of pre-exercise warm-up on performance measures, one study reported a 5% increase in distance with a high-intensity warm-up protocol (de Bisschop et al., 1999). Questions remain as to what type of pre-exercise warm-up is best suited for the majority of individuals that experience EIB or EFL and what effect on performance can be expected. Also of interest is what other ways/modes may be used to improved measures with pre-exercise warm-up.

As reviewed earlier, respiratory muscle fatigue can be a factor in the limitation and development of EFL. Johnson et al. (1993) and Miller et al. (2006) suggest that even though the diaphragm has substantial aerobic capacity, it will show significant fatigue during sustained exhaustive exercise with intensities greater than 80-85% of VO_{2max}. The force output required to sustain VE during intense exercise requires significant muscle work (O_2 demand) and a significant proportion of the cardiac output to meet the applied intensity. It has been suggested that the use of RMT or VIH (non-traditional traditional training programs) can enhance endurance exercise performance in healthy and diseased individuals (Hostettler et al., 2012). Singh et al. (2011) concluded that four-weeks of upper-body resistance training (traditional resistance training program) produced significant changes in pulmonary functions in male sedentary smokers. Thus, it would seem promising that the concept of warm-up for the respiratory muscles directly would have some merit. Throughout this review process, this author has had no knowledge of a study that has used non-traditional traditional or traditional resistance

training methods as a pre-exercise warm-up to directly warm-up the diaphragm and the accessory muscles.

Finally, a number of limitations need to be considered. First, are respiratory muscle fatigue and subsequent EFL avoidable with pre-exercise warm-up? Of the research on respiratory muscle fatigue and EFL reviewed, all involved the measure of respiratory muscle fatigue and EFL, and no study, to this author's knowledge, examined the use of pre-exercise warm-up to limit either. Second, is airway refractoriness a universal finding across individuals with and without asthma? Of the pre-exercise warm-up research, all studied individuals with some degree of asthma. It would be important to determine any effects on airway refractoriness in non-asthmatics with pre-exercise warm-up. Third, does the use of pre-exercise warm-up enhance performance? Reviewing the pre-exercise warm-up research, only two studies (of the six reviewed) attempted measured performance outcomes. Only the study by de Bisschop et al. (1999) demonstrated an increase in performance with pre-exercise warm-up. Thus, more research should focus on how exercise performance may be enhanced with the use of pre-exercise warm-up. Lastly, are there other modalities that can be used to enhance the outcomes of pre-exercise warm-up? Of the reviewed research, all pre-exercise warm-up protocols included traditional training types of activities. Could a pre-exercise warm-up using non-traditional activities (RMT, VIH or upper-body resistance training) that are directly focus on the respiratory muscles enhance pulmonary functions, but more importantly exercise performance?

Considering these areas of limitation in the reviewed research, what are the practical implications for athletes and asthmatics? As demonstrated, a pre-exercise warm-up protocol using traditional training methods showed improvement pulmonary functions in various groups of asthmatics subjects. What if this improvement could be extended to athletes that compete in

multiple events with little rest recovery in between those events? Can the duration of recovery be reduced with pre-exercise warm-up using traditional and/or non-traditional activities? Could multi-event athletes see an improvement in subsequent event performances?

In conclusion, in an effort to find more efficient ways to enhance exercise performance, this author believes an area that has shown merit is the use of a pre-exercise warm-up protocol. More specifically, the use of traditional protocols (aerobic type and HIT) combined with non-traditional protocols (RMT, VIH, and resistance training) may be the key to improved performance for athletes and asthmatics alike. Future research along these lines should be considered.

CHAPTER 2. EXPERIMENTS

2.1 Experiment 1

Introduction. Many authors have investigated respiratory system mechanics and its limitation during exercise; likewise, respiratory muscle fatigue has been examined thoroughly by measuring expiratory flow limitation (Babb, 2013; Bussotti et al., 2009; Guenette et al., 2007; Swain, Rosenkranz, Beckman, & Harms, 2010), end expiratory lung volume (DeLorey, Wyrick, & Babb, 2005; Guenette et al., 2007), exercise flow volume loops (Nourry, Deruelle, et al., 2005b), work of breathing (Guenette et al., 2007), end inspiratory lung volume (Guenette et al., 2007), maximal inspiratory pressure (Watsford, Murphy, & Pine, 2007), maximal expiratory pressure (Watsford et al., 2007), and bilateral transcutaneous supra-maximal phrenic nerve stimulation (Johnson et al., 1993). All of the above mentioned studies examined respiratory muscle fatigue during exercise except for the bilateral transcutaneous supra-maximal phrenic nerve stimulation study. The concept of respiratory system recovery after exercise has not received empirical study, for example the time it takes the respiratory system to recover to resting levels from maximal or near maximal exercise performance and the systems readiness for another maximal or near maximal exercise performance.

With the lack of research in the area of respiratory recovery after exercise, the following experiment was to examine the recovery of the respiratory system following exercise [as measured by recovery flow volume loop (RFVL) and the return to a resting level (FVL)]. The purpose of this study was to determine the effects of various exercise intensities on the measures of pulmonary function (FVC, FEV1, FEF 25-75%, and PEF) during exercise recovery. The hypothesis of this study was that following two-minutes of exercise on a bike ergometer at three different intensity levels, (40, 65, and 90% of maximal predicted heart rate) the pulmonary

function will be significantly different at 0, 5, 10, and 20-minute post exercise recovery in young healthy individuals.

Methods. Ten subjects on separate days at least 24-hours apart (five males and five females) ages 18-32 (mean 22.6 years) performed two minutes of exercise at three different trial intensities (40, 65, and 90% of maximal predicted heart rate) on an electronic braked cycle ergometer (Ergometrics 800, Sensormedics). Subjects were instructed and self-reported that they refrained from exercise, caffeine, and alcohol for 24-hours and had not eaten whole foods three hours before testing. A 1.5-mile run for time was completed by the participants to estimate their VO_{2max} (George, Vehrs, Allsen, Fellingham, & Fisher, 1993; Larsen et al., 2002). Pulmonary function via spirometry testing (FVC, FEV1, FEF 25-75%, and PEF) and cardiovascular [heart rate, blood pressure, and blood oxygen saturation (SpO_2)] data were measured before, during, and after (0, 5, 10, and 20-minutes intervals) each exercise trial. The study was conducted in a university-based kinesiology laboratory and the subject population of the study was drawn from university student volunteers enrolled in Human Performance Education courses. Within the study, volunteered subjects were excluded based on health status from the Physical Activity Readiness Questionnaire (ParQ) (individuals with asthma, smokers, pregnant females, and others that maybe at risk for exercise conditions were excluded). Volunteered subjects were informed of the potential risks of the study and their written informed consent was given to participate prior to beginning the study. This study was approved by the University's Institutional Review Board for use of human subjects (see Appendix).

Study Design. Subjects were randomly selected for trial conditions and completed an informed consent form, a ParQ, a 1.5-mile run, and demographic assessments were collected (height, weight, body compositions via bioelectrical impedance- Omron® HBF 306C, Omron,

Table 2.1.1: Demographics for Experiment 1.

Gender	5 males, 5 females
Age	22.6±9.4
Height inches	67.15±7.2
Weight pounds	153.8±66.2
Body Mass Index	23.673±7.2
Percentage of Body fat	17.98±12.9
Estimated VO_{2max}	43.341±14.8

Corp., Schaumburg, IL) (Lukaski, Bolonchuk, Hall, & Siders, 1986) prior to spirometry testing. Upon arriving for their testing, subjects were issued a single use Microgard® Disposable Filter and performed resting spirometry followed by the randomized condition trial. Spirometry trials were repeated as needed to achieve ATS standards for spirometry testing. Data from each subject (spirometry, BP, HR, SpO_2) was collected at each timed interval (0, 5, 10, and 20-minutes). Subsequent testing days followed with at least 24-hours in between trials. The subject's heart rate and SpO_2 data was monitored by pulse oximetry (Nonin® 8600 pulse oximeter, Nonin Medical Inc., Plymouth, MN). Once the resting spirometry data was collected, subjects assumed the seated position (seat adjusted to approximately 30º of knee flexion) on the bike ergometer and began pedaling to maintain a speed greater than 60 rpm for two-minutes. Pedaling resistance was added to increase the subject's HR to the required max predicted HR (40, 65, and 90% of maximal predicated heart rate) for at least the last 30-seconds of each bike trial. Resistance was adjusted as needed to keep the subject's HR and pedaling rpm in protocol ranges. Once the bike trial was completed, the subject immediately sat down, donned provided nose clips, and began the recovery spirometry testing. Recovery testing protocols were completed after the 20-minutes of data collection interval.

Pulmonary Function Measurements. Spirometry measures were forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), forced expiratory flow 25-75% (FEF 25-75%), and peak expiratory flow (PEF). Sensormedics Vmax® 29c Pulmonary

Function/Cardiopulmonary Exercise Testing Instrument was used to collect the spirometry values and the instrument (flow and volume sensor) was calibrated daily following American Thoracic Society (ATS) accuracy standards (M. R. Miller et al., 2005). The laboratory atmospheric ranges are as follows: 1) temperature 68-74° F, 2) 60-70% relative humidity, and 3) barometric pressure 758-766 mmHg. Infection control was managed by instructing subjects to wash hands upon entering the lab and each subject was assigned a sealed bag for their single use Microgard® Disposable Filter. During all spirometry measurements, subjects were required to sit with their noses clipped, and instructions were given by an experienced technician on the task needed. All testing criteria followed ATS evaluation standards (M. R. Miller et al., 2005).

Data Analysis. With demographic data gathered prior to testing (age, gender), dependent variables, such as included spirometry data (FVC, FEV_1, FEF 25-75%, and PEF), anthropometric data (mass, stature body fatness and body mass index), and a timed 1.5-mile run (predicted VO2) were utilized during the study. The independent variables were 40%, 65%, and 90% MPHR, and a timed post exercise (0, 5, 20, and 20-minutes). Following experimentation, one-way repeated ANOVA measures were computed across the independent variables for each respiratory measure and timed runs in order to determine if respiratory capacities had changed. The criterion for statistical significance of the correlations was set at $p \leq 0.05$. All statistical tests were performed on SPSS version 21.0 (Chicago, IL, U.S.A.).

Results. Pulmonary capacities did not change significantly based on the intensity of the exercise performed. There were no pulmonary function differences found at 0, 5, 10, or 20-minute post exercise recovery times. The cardiovascular responses were normal.

Discussion. The purpose of this study was to determine the effects of various exercise intensities (40, 65, and 90% of maximal predicated heart rate) on the measures of pulmonary

Table 2.1.2: ANOVA comparisons between conditions and time

Variable	N	Condition F	Condition p	Time F	Time p
FVC	10	0.411	0.745	0.049	0.995
FEV1	10	1	0.393	1	0.409
FEF 25-75%	10	0.253	0.859	0.252	0.908
PEF	10	0.228	0.877	0.204	0.936

Note: Significance at $p \leq 0.05$*

function (FVC, FEV1, FEF 25-75%, and PEF) during exercise recovery; and it was hypothesized following two-minutes of exercise on a bike ergometer at three different intensities, (40, 65, and 90% of maximal predicated heart rate) the pulmonary function will be significantly different at 0, 5, 10, and 20-minute post-exercise recovery in young healthy individuals. The data suggests there were no statistical difference between the pulmonary function measures at the various exercise intensities tested.

Some possible areas of weakness of the study includes the limited sensitivity of pulmonary function for the exercise intensities utilized and the exercise trial duration were not extensive enough to cause changes in the respiratory system. Other sensitive methods may be used to determine greater significance in distinguishing a change in an individual's respiratory system during exercise. Nourry et al. (2005) used maximal flow-volume loop (MFVL) at rest and the exercise flow-volume loops (EFVL) (plotted in the MFVL) during a progressive exercise test to exhaustion (eight to ten-minute duration). The results of the study showed higher FVC and maximal expiratory flows in trained subjects' verses untrained subjects' thus suggesting that EFVL may be a more sensitive method in seeing change in pulmonary function measures. Hill et al. (1991) studied a group of triathletes to see what pulmonary function measures changed during an endurance triathlon (long duration, multi-event). Pulmonary functions were obtained after each event and 24 hours after the completed triathlon. Following the completion of the triathlon, significant declines from baseline were noted in the FVC (7.1%), FEV_1 (8.4%), FEF 50% (18.6

%), FEF 25-75% (15.2%), but no change in MVV or the other FEF measures, ratio, and/or PEF were demonstrated. These results suggest the duration (>12-hours) of the exercise is an important variable reflective of declines in some pulmonary function measures. Though this study illustrates long durations of exercise affecting pulmonary function of triathletes, it remains to be determined at what timed interval the variables started to decline; it seems base on the present studies protocols, it would be longer durations of greater than two-minutes.

There are limitations within this study, such as the control of intensity was difficult to monitor because of the short duration of the activity protocol (two-minutes) and the adjustment of intensity via manual resistance produced the heart rate to respond slower than the subjects' fatigue. A longer duration of exercise time may have helped to control for this limitation and allow a more comfortable ramping of the intensity. Secondly, the maximum (zero-minutes after trial) recovery PFT was difficult to obtain for the 90% intensity protocol because most subjects were breathing maximally and it was challenging to complete the PFT when subjects are gasping for breath. An alternative to this limitation would have been to do a peak flow at the maximum recovery and complete the first PFT at one minute of recovery. Lastly, the possibility that the number of subjects in this study could weaken the statistical reliability can never be discarded.

Conclusion. Exercise trials for two-minutes, at intensities of 40, 65, and 90% of their maximum predicted heart rate, are not significantly taxing enough to produce changes in pulmonary function measures in young healthy individuals. Though the data does not show significant changes in pulmonary function measures with short durations of exercise with varying intensity, the beneficial effects of such cannot be ruled out.

2.2 Experiment 2

Introduction. Many exercise physiologists believe the respiratory system has little to no effect on limiting exercise performances in healthy individuals or athletes (A. McConnell, 2009), yet the respiratory system encounters several challenges during intense exercise. For example, the regulation of alveolar partial pressure of oxygen and carbon dioxide is achieved by a considerable increase in alveolar minute ventilation (V_E) often 20-times the resting value in humans. This large increase in V_E is achieved by the capacity of the respiratory muscles to not only generate forces to alveolar ventilation but also by limiting excessive physiological cost on the system during exercise (Guenette & Sheel, 2007). An additional challenge the respiratory system must overcome is the ability of the bronchial (intra-thoracic) airways to maintain patency to allow the increase flow rate needed during active expiration often seen in intense exercise. During high intensity exercise, the bronchial airways occasionally do present a significant limitation to expiratory flow; thereby causing dynamic hyperinflation, increased respiratory muscle work, and V_E limitation (Forster et al., 2012).

Research on the value of pre-exercise warm-up has used only traditional training protocols and methods [high intensity interval (HIT), continuous low intensity (CLI), and continuous high intensity (CHI)] as the warm-up modes. Another possible way to reduce the demand on the respiratory system's muscles and change pulmonary function is the use of a pre-exercise respiratory warm-up involving non-traditional training methods. Non-traditional methods use respiratory muscle training devices (inspiratory and expiratory breathing methods) to warm-up the respiratory muscles. Based on my literature review, no studies have used non-traditional warm-up methods to warm-up before exercise performance, but some studies have

looked at the training effect of these types of training protocols (Griffiths & McConnell, 2007; Singh et al., 2011; Weiner et al., 1992) on pulmonary functions.

Weiner et al. (1992) compared specific inspiratory muscle training versus sham (placebo) training on inspiratory muscle strength and endurance in an adult bronchial asthma population. The study observed increases in inspiratory muscle strength and endurance as well as increases in the FVC (force vital capacity) and the FEV_1 (forced expiratory volume in one second) when compared to the sham control group with six months of training. Griffiths and McConnell (2006) investigated the effect of four-weeks of inspiratory muscle training and/or expiratory muscle training and the subsequent effects of a six-week trial of combined inspiratory and expiratory muscle training in club-level oarsmen on rowing performance. The results of the study suggested an increase in inspiratory and expiratory muscle strength and improvements in mean power rowing performance. Singh et al. (2011) examined the effect of upper-body resistance training and conventional deep breathing exercises on pulmonary function in male smokers. Results from the study indicated improvements in pulmonary functions (FEV_1 and FEV_1/FVC). These studies suggest the use of non-traditional methods of training as an effective way to improve pulmonary function, inspiratory and expiratory muscle strength, and exercise performance.

The physiological and performance benefits demonstrated by the previous reviewed studies of non-traditional methods of training are hypothesized to also benefit an individual's pulmonary functions and exercise performance when used as a pre-exercise warm-up. The aim of this study was to determine which of the three conditions (inspiratory, expiratory, or combined) produced the best and most intense warm-up as assessed by rating of perceived exertion (RPE) for breathing, produced positive (increases) change in PF measures, and produced the most favorable recovery interval for PF measures. Of the three warm-ups (i.e. IM, EM, and CM), it

was hypothesized the CM would stress the respiratory muscles to a greater degree (i.e. CM would produce a higher RPE during the performance); and for all three warm-ups, respiratory muscles will recover in ten-minutes (i.e. have the highest PF during recovery).

Methods. Ten male subjects (Table 2.2.1) aged 18 to 30 (mean 22.6 years) completed each of the three warm-ups 24-hours apart. Subjects were instructed and self-reported that they refrained from exercise, caffeine, and alcohol for 24-hours and had not eaten whole foods three hours before testing. The study was conducted in a university-based kinesiology laboratory and the subject population was drawn from university student volunteers (convenience sample). Subject inclusion was only male subjects while exclusion was based on volunteers' health status from the Physical Activity Readiness Questionnaire (ParQ) (individuals with asthma, smokers, and others that maybe at risk for exercise treatments were excluded). In addition, demographic assessment (height, weight, body compositions via bioelectrical impedance- Omron® HBF 306C, Omron, Corp., Schaumburg, IL) (Lukaski et al., 1986) was completed prior to beginning the study for use of standardizing subjects. The study was approved by the University's Institutional Review Board for use of human subjects (see Appendix).

Table 2.2.1: Demographics for Experiment 2.

Gender	10 males
Age	22.6±7.4
Height inches	68.2±5.2
Weight pounds	162.0±115.2
Body Mass Index	27.36±11.24
Percentage of Body fat	17.77±16.73

Study Design. Subjects practiced each randomly selected warm-up on separate days for a duration of five-minutes (actual breathing) while seated with a nose clip on. After each one-minute interval of the five-minute warm-up, subjects were asked to give a rating of perceived exertion of breathing (RPE 1-10 point scale, Appendix 1.D.) and performed a peak flow (PF)

through a peak flow measuring device. Fifteen-second duration was allowed to complete the RPE and PF measurement and then the warm-up continued. Each randomized warm-up was performed for a total duration of six-minutes once the fifteen-seconds were added to assess the RPE and PF at each one-minute interval. PF data were recorded up to ten minutes (1, 2, 3, 4, 5, 6, 8, and 10-minute intervals) following completion of warm-ups and was labeled as recovery.

Breathing Warm-ups. The three respiratory warm-ups/ treatments performed for this study were: inspiratory (IM), expiratory (EM), and combined inspiratory and expiratory (CM) conditions. For IM, subjects inhaled deeply and forcefully to inspiratory capacity (IC) at a rapid flow on an incentive spirometer (IS) device that measured inspiratory volume while providing visual feedback on high, medium, and low flow generated. Following inhalation, subjects were asked to hold their breath for five-seconds, and then exhale slowly with a moderate force to residual volume (RV). In EM, subjects were asked to inhale slowly to IC, hold their breath for five-seconds and then exhaled forcefully at a rapid flow to RV through a Resistex® Mercury® Resistance Exercisers (RM) device with variable expiratory resistive load setting [one to four (minimum to maximum)]. The expiratory resistive load was on four for each subject. For CM, subjects were asked to inhale deeply and forcefully to IC at a rapid flow on the IS device, hold their breath for five-seconds, and then exhaled forcefully at a rapid flow through RM device to RV. All warm-ups were practiced for five-minutes (actual breathing) in a seated position and wearing nose clips.

Data Analysis. RPE and PF were the dependent variables in this study while the independent variables were the warm-ups/treatments (IM, EM, and CM). Following experimentation, paired sample t-tests were calculated to compare data from pre-warm-up to

during warm-up (Table 2.2.2). The criterion for statistical significance of the correlations was set at $p \leq 0.05$. All statistical tests were performed on SPSS version 21.0 (Chicago, IL, U.S.A.).

Results. As noted in Figure 2.2.1, CM produced an increase in PF after five-minutes of the warm-up. In addition, CM resulted in a reasonably consistent pattern of increasing PF values. The IC displayed a consistent decline throughout the warm-up period, but the EC had erratic response up and down throughout. The data from the RPE during warm-ups are presented in Figure 2.2.2. RPE displayed progressively increased throughout each warm-up with CM resulted in the highest RPE value after five-minutes. The data in Figure 2.2.3 suggests the highest PF values were achieved at four minutes of recovery for all warm-up conditions. PF decreased after four minutes for all three warm-ups with CM remaining the highest at eight and ten minutes of recovery. Overall, however, the pattern between warm-up procedures was the basically the same for each procedure.

The paired sample t-test suggests there was a significant difference in the CM warm-up at RPE4 (M=3.800, SD=1.398) and RPE5 (M=4.500, SD 1.509); t(9) =-3.280, p=0.010. No other variable found statistically significance (Table 2.2.2).

Discussion. Although this is the first known study to investigate breathing warm-up effects on RPE and PF, the aim of this study was to determine which of the three warm-ups (IM, EM, or CM) produced the best and most intense warm-up as assessed by the rate of perceived exertion (RPE) for breathing, producing positive (increases) change in PF measures. In addition, the most favorable recovery interval is for determining how PF measures were investigated. It was hypothesized that among the three warm-ups, CM would stress the respiratory muscles to a greater degree (i.e. higher RPE during the performance) and regardless of the warm-up, the respiratory muscles will recover in ten-minutes (i.e. highest PF observed during recovery).

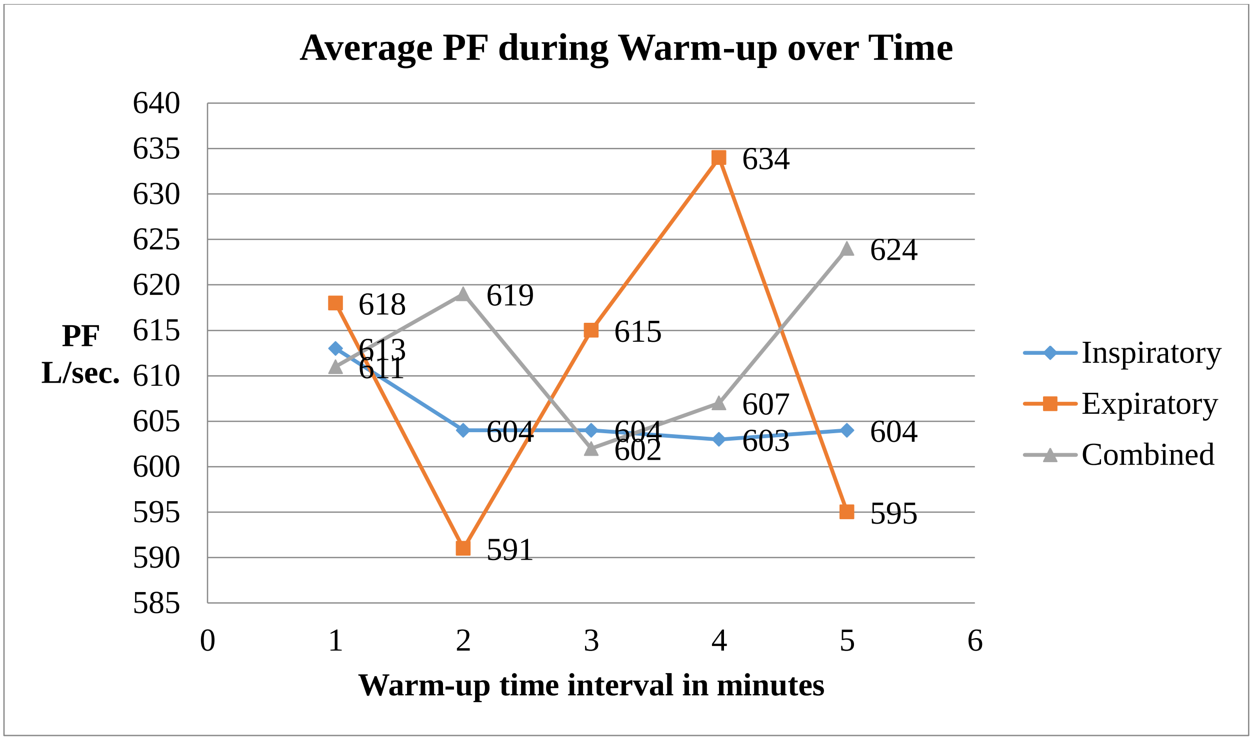

Figure 2.2.1: Average PF during time interval for warm-ups.

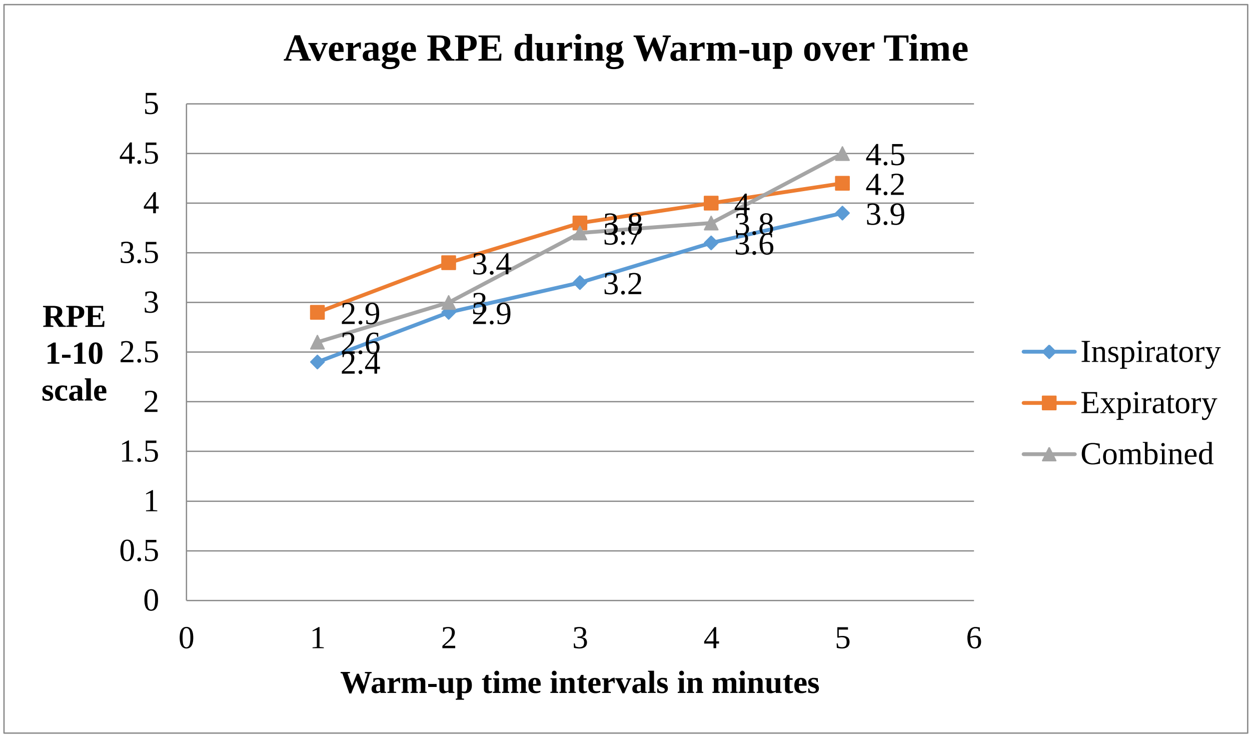

Figure 2.2.2: Average RPE during warm-up time interval.

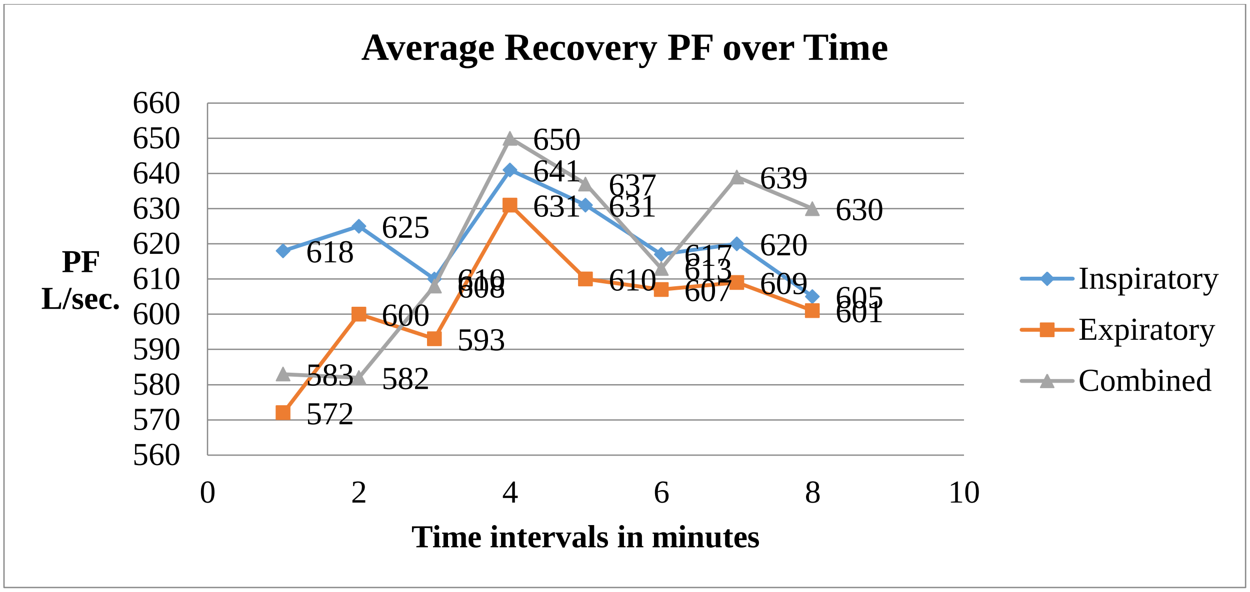

Figure 2.2.3: Average recovery RPE time interval.

Table 2.2.2: T-test data for Peak Flow and RPE during warm-up: IM=Inspiratory, EM=Expiratory and CM= Inspiratory/Expiratory

Condition		N	Mean	Std. Deviation	t	df	Sig. (2-tailed)
Peak Flow (PF)							
IM	Pre-PF	10	607.5000	73.68288	0.112	9	0.913
	PF5	10	604.5000	117.05768			
EM	Pre-PF	10	616.5000	75.57373	1.342	9	0.212
	PF5	10	595.5000	66.35134			
CM	Pre-PF	10	591.0000	81.16513	-1.637	9	0.136
	PF5	10	624.5000	102.91447			
Peak Flow (PF)							
IM	PF1	10	613.5000	79.16404	0.424	9	0.681
	PF5	10	604.5000	117.05768			
EM	PF1	10	618.0000	73.15129	1.317	9	0.220
	PF5	10	595.5000	66.35134			
CM	PF1	10	611.0000	89.00062	-0.566	9	0.585
	PF5	10	624.5000	102.91447			
Rating of Perceived Exertion Breathing (RPE)							
IM	RPE4	10	3.6000	1.34990	-1.964	9	0.081
	RPE5	10	3.9000	1.59513			
EM	RPE4	10	4.0000	1.12472	-1.500	9	0.168
	RPE5	10	4.2000	1.22927			
CM	RPE4	10	3.8000	1.39841	-3.280	9	0.010*
	RPE5	10	4.5000	1.50923			

Note: Significance at $p \leq 0.05$*

Pre-PF= resting PF, PF1= PF at 1-minute of the treatment, PF5= PF at 5-minutes of the treatment, RPE4= RPE at 4-minutes of the treatment, RPE5= RPE at 5-minutes of the treatment.

The data in Figure 2.2.1 suggest the PF during the three warm-ups differed at the end of five-minutes of treatment. The CM resulted in an increase in PF after five-minutes while producing a reasonably consistent pattern of increasing PF values to the end of treatment. The CM protocol required forced inhalation and exhalation on the breathing cycle thereby emphasizing the use of inspiratory and expiratory muscles. IC and EC protocols only required forced inhalations or exhalations, respectively, therefore emphasizing one side of the breathing cycle. Because the CM utilized a two sided use of the respiratory muscles, it is believed that work created greater airway flow than the other single sided respiratory movements (IC and EC). Movements such as these increase the range of motion of the respiratory muscles allowing for greater preparation of the respiratory system for subsequent forced inhaling and exhaling as seen in the PF maneuver.

The information provided in Figure 2.2.2 is suggestive of RPE progressively increasing throughout each warm-up with CM resulting in the highest RPE value after five minutes. The paired sample t-test is supportive for this outcome suggesting an increase that is statistically significance in the CM at RPE4 vs. RPE5. Since there is an effect in the CM forced inspiratory and forced expiratory, an increased intensity is created across the breathing cycle. Even though all warm-ups use the complete breathing cycle, the forced nature of the CM provides an increased intensity. However, it should be noted real number differences between the warm-ups RPE are small (3.9 IM, 4.2 EM, 4.5 CM).

The data from Figure 2.2.3 shows all warm-ups progressively increased PF values at one minute of recovery up to a peak PF value at four minutes of recovery with PF values decreasing afterwards. At the eight and ten minute timeframe of recovery, the PF of CM remained the highest of the three warm-ups. These findings continue to suggest the two-sided force

involvement of the respiratory muscles in the CM warm-up allows the system to stay primed longer.

Some limitations of this study include the calculations and comparisons were made with in each of the warm-ups (i.e. CM, Pre-PF to CM PF5) and not across warm-ups (i.e. IM to CM). Secondly, the use of PF maneuvers can display a large range of values based on the subjects' effort as shown in figure 2.2.1. Thirdly, EC resulted in an inconsistent pattern related to poor stability in subjects' effort. More consistent coaching of the PF maneuver and repeat efforts for the best value would help to alleviate these inconsistences. Lastly, the small sample size weakens the statistical reliability.

Conclusion. For each of the three warm-ups, five-minutes appeared to be a sufficient duration to benefit breathing without greatly challenging body systems (RPE of a proximally 4). During CM, the PF increased from the start of the treatment and had a reasonable consistent pattern after five-minutes. On the other hand, IM and EM decreased at the end of five-minutes. In recovery, all conditions achieved their highest values at four-minutes and continually decreased afterwards. Notwithstanding this decrease, CM remained the highest at ten-minutes of recovery. Based on these findings, the CM appears to be the optimal breathing warm-up for the experiments that follow.

2.3 Experiment 3

Introduction. Many exercise physiologists believe that the respiratory system has little to no effect on limiting exercise performances in healthy individuals or athletes (A. McConnell, 2009), yet the respiratory system encounters several challenges during intense exercise. One example is the regulation of alveolar partial pressure of oxygen and carbon dioxide is achieved by a considerable increase in alveolar minute ventilation (V_E) often 20-times the resting value in

humans. This large increase in V_E is achieved by the capacity of the respiratory muscles to not only generate forces to alveolar ventilation but also by limiting excessive physiological cost on the system during exercise (Guenette & Sheel, 2007). Another example challenging the respiratory system one must overcome is the ability of the bronchial (intra-thoracic) airways to maintain patency in order to allow the increase flow rate needed during active expiration often seen in intense exercise. During high intensity exercise, the bronchial airways, occasionally, do present a significant limitation to expiratory flow; therefore, causing dynamic hyperinflation, increased respiratory muscle work, and V_E limitation (Forster et al., 2012).

An often-overlooked ingredient to a possible limitation of the respiratory system is how the mechanical work of breathing has both sensory and metabolic repercussions. The perceived work of breathing contributing to how hard the exercise feels (sensory) and the demands the mechanical work of breathing places on the circulatory system for blood and oxygen to sustain muscle contraction (metabolic) (A. McConnell, 2009). It has been suggested that the metabolic and circulatory cost of a high mechanical work of breathing during maximal levels of V_E can amount to 8-10% of the VO_{2max} (maximal oxygen consumption) and cardiac output in the untrained individual and up to 14-16% of VO_{2max} and cardiac output in highly-trained individuals (Aaron et al., 1992; Harms, McClaran, et al., 1998). It is further noted, with research on blood flow distribution, as the respiratory muscles are loaded, a reflex vasoconstriction is produced resulting in decreased blood flow to the exercising limb. Conversely, when the respiratory muscles were unloaded, a state of increased blood flow (dilation) existed in the exercising limb muscles (Harms, Wetter, et al., 1998). This change in limb blood flow indicates a competitive relationship between the muscles of locomotion and the muscles of respiration for limited cardiac output (Guenette & Sheel, 2007). These findings may well represent the

respiratory system's challenge to sustain airway patency in the face of maximal or near maximal workloads, creating high V_E demands, competition for the available cardiac output with limb muscles, and variations in the respiratory muscles fatigue states.

Research on the value of pre-exercise warm-up has used only traditional training protocols and methods [high intensity interval (HIT), continuous low intensity (CLI), and continuous high intensity (CHI)] as the warm-up mode (McKenzie et al., 1994; Reiff et al., 1989; Schnall & Landau, 1980). Reiff et al. (1989) examined the effect of a prolonged warm-up period of exercise on subjects with exercise induced asthma (EIA) and found that both CLI and CHI warm-ups suggest a benefit (protection from EIA) for their subjects. McKensie et al. (1994) examined the protective effects of CLI warm-up and an interval warm-up (IW) exercise on post-exercise bronchoconstriction in athletes with EIA and their findings suggest the CLI protocol was significantly better than an IW protocol, but the IW was still significantly better than the control group. Schnall et al. (1980) examined the notion of bronchodilation produced by short periods of running (HIT) in subjects in which EIB had occurred after a standard exercise test. Their findings are suggestive that the use of repeated, short runs minimize the EIB and had a bronchodilating effect on previous EIB. Their research also suggest that the data provides evidence to support asthmatics cope better with repeated, short duration activities (HIT) and a warm-up period may be beneficial in alleviating the effects of more prolonged exercise. These studies suggest the use of traditional training protocols as a pre-exercise warm-up providing subjects with a positive change in their pulmonary function and reduced EIB.

Another possible way to reduce the demand on the respiratory system's muscles and change pulmonary function is the use of a pre-exercise respiratory warm-up that involves non-traditional training methods. Non-traditional methods would use respiratory muscle training

devices (inspiratory and expiratory muscle methods) to warm-up the respiratory muscles. Based on this author's literature review, there are not any studies researched on non-traditional warm-up methods to warm-up before exercise performance, but some studies have looked at the training effect of these types of training protocols (Griffiths & McConnell, 2007; Singh et al., 2011; Weiner et al., 1992) on pulmonary functions. Weiner et al. (1992) compared specific inspiratory muscle training versus sham training on inspiratory muscle strength and endurance in an adult bronchial asthma population. Observation of increases in inspiratory muscle strength and endurance was found as well as increases in the FVC (force vital capacity) and the FEV_1 (forced expiratory volume in one-second) when compared to the sham control group with six-months of training. Griffiths and McConnell (2006) investigated the effect of four-weeks of inspiratory muscle and/or expiratory muscle training and the subsequent effects of a six-week trial of combined inspiratory and/or expiratory muscle training in club-level oarsmen on rowing performance. The results of the study indicate an increase in inspiratory and expiratory muscle strength along with improvements in mean power rowing performance. Singh et al. (2011) examined the effect of upper-body resistance training and conventional deep breathing exercises on pulmonary function in male smokers. The results indicated improvements in pulmonary function (FEV_1 and FEV_1/FVC). These studies suggest the use of non-traditional methods of training are an effective way to improve pulmonary function test, inspiratory and expiratory muscle strength, and exercise performance.

Since traditional training methods used as a pre-exercise warm-up demonstrate positive change in pulmonary function and performance, one may conclude a non-traditional method of training used as pre-exercise warm-up may demonstrate similar benefits. The concept of non-traditional methods used as a pre-exercise warm-up for the respiratory muscles to improve

pulmonary function and exercise performance is a novel idea and worthy of investigation. As such, if a breathing warm-up can increase the mechanical advantage of the respiratory muscles prior to exercise, subjects may reduce the oxygen and cardiac output requirements during the initial stages for exercise. If oxygen consumption and cardiac output requirements of the respiratory muscles can be reduced during the initial stages of exercise performances than one might expect to appreciate a recovery benefit as well. Based on the results from experiment two in this study, the combined inspiratory and expiratory breathing condition/warm-up (IEC from here on) suggested better outcomes (most intense and increased PF) compared to either of the other conditions inspiratory (IC) and expiratory (EC) studied alone. As such, this experiment is an expanded examination of the IEC (warm-up) effect on performance, rating of perceived exertional breathing, and pulmonary function. The aim of this study is to evaluate the impact of a pre-exercise respiratory warm-up using non-traditional methods (combined inspiratory and expiratory muscle training modalities) (IEC) on pulmonary function measures (FVC, FEV_1, FEF 25-75%, PF), performance time (300-yard shuttle and 1.5-mile run) and recovery rating of perceived exertion (RPE) breathing. Thus, it is hypothesized the use of a pre-exercise respiratory warm-up using non-traditional methods (combined inspiratory and expiratory muscle training modalities) will increase pulmonary function measures (FVC, FEV_1, FEF 25-50%, PEF) and increase performance (reduced time to completion) achieved in a 300-yard shuttle and the 1.5-mile run as compared to the control condition (CC) (no warm-up). A secondary hypothesis is that fitness status of the subjects would not be related to decreases in performance time and subjects would rate their perceived exertion of breathing (RPE 1-10 point scale, Appendix 1.D.) level as lower during recovery from each run after the respiratory warm-up (IEC).

Methods. All twenty male subjects the study aged 20 to 34 (mean 24.3-years) completed the four sessions of the study (Table 2.3.1). In addition, two subjects started the sessions but were not able to complete the entire study because of scheduling conflicts; therefore, their data was not incorporated into this experiment. The study was conducted in a university-based kinesiology laboratory and gymnasium with the subject population was drawn from university student volunteers (convenience sample). Subject inclusion was only male subjects while exclusion was based on volunteers' health status from the Physical Activity Readiness Questionnaire (ParQ) (individuals with asthma, smokers, and others that maybe at risk for exercise treatments were excluded). Subjects were informed of the potential risks and gave their written informed consent to participate prior to beginning the study. This study was approved by the University's Institutional Review Board for use of human subjects (see Appendix).

After completion of the informed consent, ParQ, and baseline data (height, weight, body fatness percent via bioelectrical impedance- Omron® HBF 306C, Omron, Corp., Schaumburg, IL) (Lukaski et al., 1986) for standardizing subjects, all subjects performed an initial series of resting PFT followed by a randomly assigned resting (no-warm-up) control condition (CC) for five-minutes or respiratory warm-up for five-minutes using the IEC warm-up protocol. Subjects were instructed to perform the respiratory warm-up as follows: 1) Inhale deeply and forcefully to inspiratory capacity (IC) at a rapid flow on an incentive spirometer (IS device- measures inspiratory volume while visually giving feedback on high, medium, and low flow generated); 2) Hold the inhale (breath) for five-seconds; 3) Exhale forcefully at a rapid flow to residual volume (RV) through the Resistex® Mercury® Resistance Exercisers (RM) device with variable expiratory resistive load setting (set at 4 highest resistance) to RV. Once the five-minutes of CC (no warm-up) or IEC (warm-up) was completed, subjects rested for five-minutes and then

performed a 300-yard shuttle run (50-yards each direction) (Cumming & Keynes, 1967) or a 1.5-mile run (running line for a consistent distance) (Larsen et al., 2002) for time in a gymnasium [all subjects completed both the CC (no warm-up) and IEC (warm-up) on different days for both runs]. Subjects were allowed limited self-directed stretching before runs. After completion of the runs, subjects returned to the kinesiology lab for recovery testing starting with PF and RPE for every minute for 15-minutes. At the 5, 10, and 15-minute intervals PFT data was collected. During each assessment interval subjects were seated and nose clipped. The test sequence required four days (two days for CC and two days for IEC) for completion. All subjects completed two 300-yard shuttle runs (one with warm-up, one without) and two 1.5-mile runs (one with warm-up, one without). Subjects were instructed and self-reported that they refrained from exercise, caffeine, and alcohol for 24-hours and had not eaten whole foods three hours before testing. Testing sessions were 24-hours apart. Fitness status was determined by predicting the subject's VO_{2max} from their best 1.5-mile run time (George et al., 1993; Larsen et al., 2002).

Table 2.3.1: Demographics for Experiment 3.

Gender	20 males
Age	24.2±9.8
Height inches	68.1±5.1
Weight pounds	163.5±76.5
Body Mass Index	24.6±16.2
Percentage of Body fat	11.7±10.9
Estimated VO_{2max}	44.9±14.9

Pulmonary Function Measurements. Spirometry measures utilized were forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), forced expiratory flow 25-75% (FEF 25-75%) and peak expiratory flow (PEF). All pulmonary measurements were made with a Sensormedics Vmax® 29c Pulmonary Function/ Cardiopulmonary Exercise Testing Instrument. The instrument's (flow and volume sensor) were calibrated daily following American Thoracic

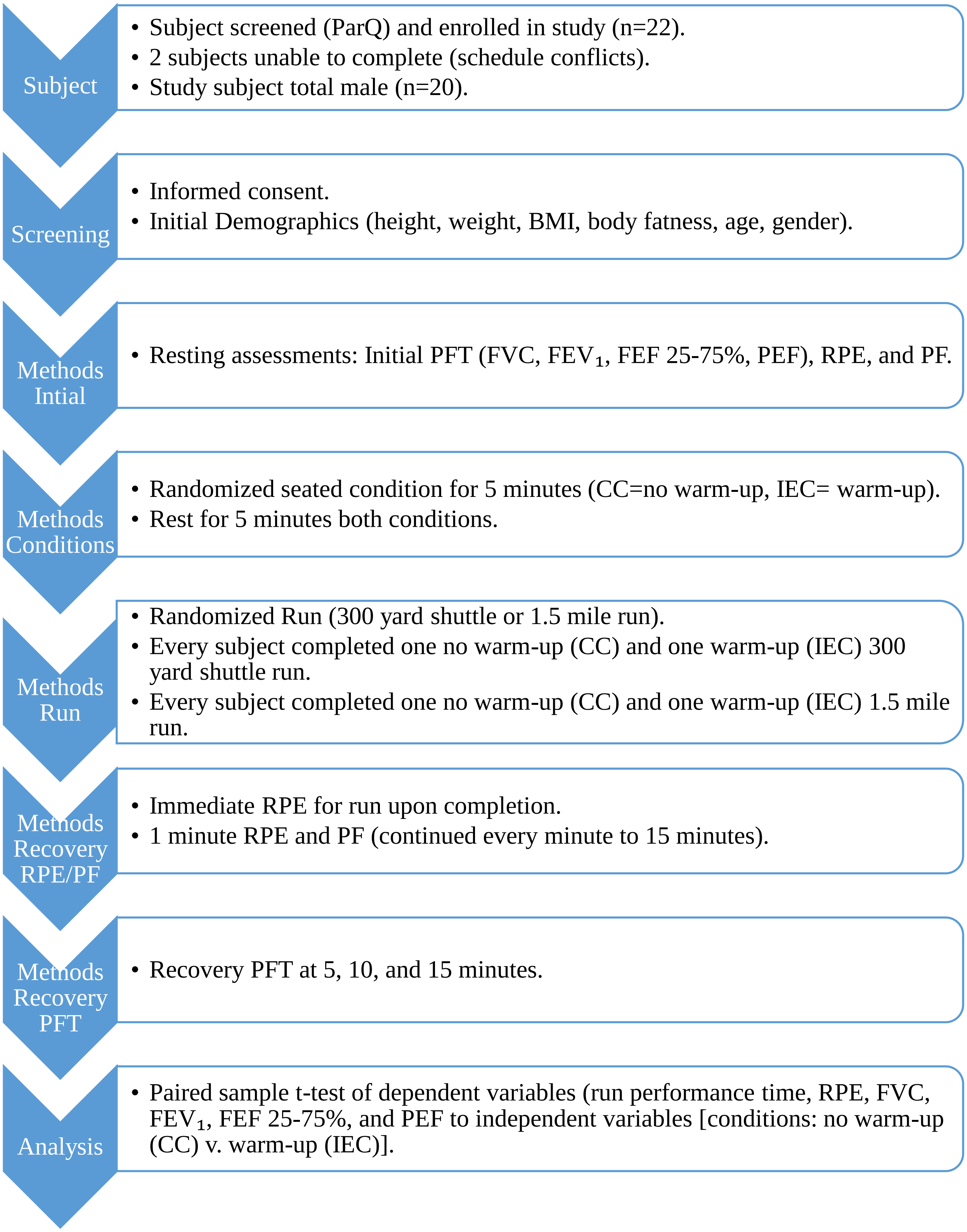

Figure 2.3.1: Flow chart of subjects, interventions, and analysis.

Society (ATS) accuracy standards (M. R. Miller et al., 2005). The laboratory atmospheric ranges were as follows: 1) temperature 68-74° F, 2) 60-70% relative humidity, and 3) barometric pressure 758-766 mmHg. Infection control was managed by instructing subjects to wash their hands upon entering the lab and each subject was assigned a sealed bag for their assigned Microgard® Disposable Filter that was used only by them for each spirometry test. During all measurements, subjects were seated, their nose was clipped, and they were instructed on proper testing technique by an experienced technician. All testing criteria followed the ATS evaluation standards (M. R. Miller et al., 2005).

Data Analysis. The dependent variables included performance time, RPE, FVC, FEV_1, FEF 25-75% and PEF and the independent variables are the conditions no warm-up (CC) and warm-up (IEC). Following experimentation, paired sample t-tests were calculated to compare no warm-up (CC) and warm-up (IEC) data. Additional, VO_{2max} was plotted against percent of improvement for run times. The criterion for statistical significance of the correlations was set at $p \leq 0.05$. All statistical tests were performed on SPSS version 21.0 (Chicago, IL, U.S.A.).

Results. There was a significant difference in the 300 yard shuttle run as shown in Figure 2.3.2 for the immediate post run RPE between no warm-up (CC) (M= 8.65, SD=0.587) and warm-up (IEC)(M=9.1, SD=0.718); t(19)=-2.269, *p*=0.035, the two-minute recovery RPE no warm-up (CC) (M=6.15, SD=1.268) and warm-up (IEC) (M= 6.8, SD=1.508); t(19)=-3.115, *p*=0.006, and the seven-minute RPE no warm-up (CC) (M= 3.5, SD=1.235) and warm-up (IEC) (M=4.05, SD=1.356); t(19)=-2.463, *p*=0.024. No other paired sample showed significance for RPE recovery in the 300 yard shuttle run as well as in Figure 2.3.3 for the 1.5 mile run. Data in Figure 2.3.4 suggest no relationship between VO_{2max} and the percentage of improvement in performance time for the 300-yard shuttle and 1.5-mile run.

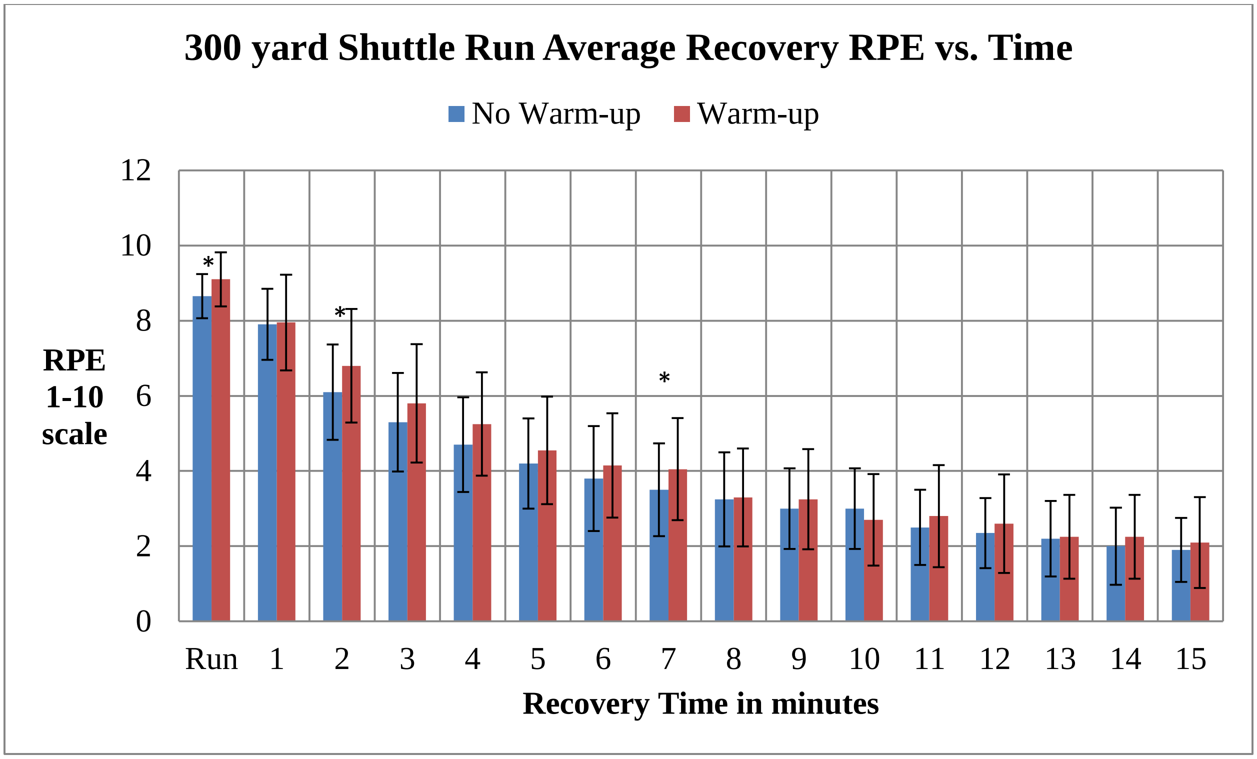

Figure 2.3.2: Average recovery RPE for the 300-yard shuttle run comparing no warm-up (blue bar) and warm-up (red bar) with standard deviations and significance at $p \leq 0.05$*.

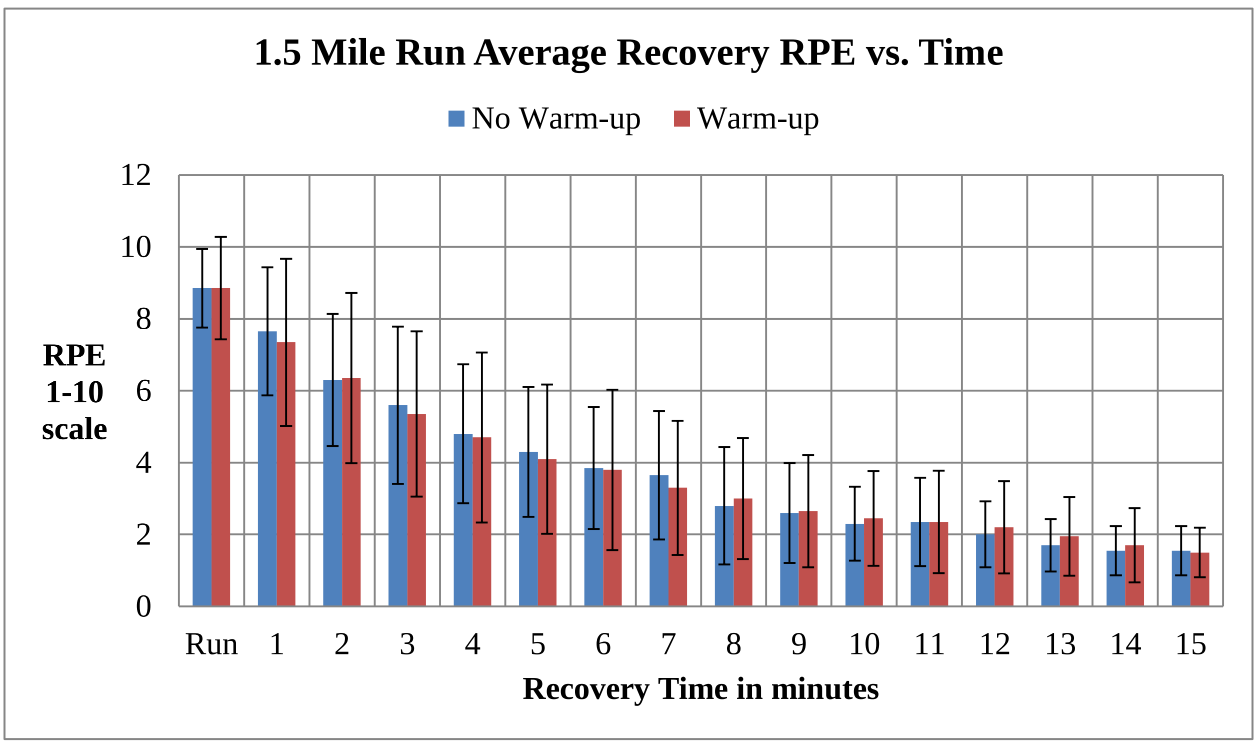

Figure 2.3.3: Average recovery RPE for the 1.5-mile run comparing no warm-up (blue bar) and warm-up (red bar) with standard deviations and significance at $p \leq 0.05$*.

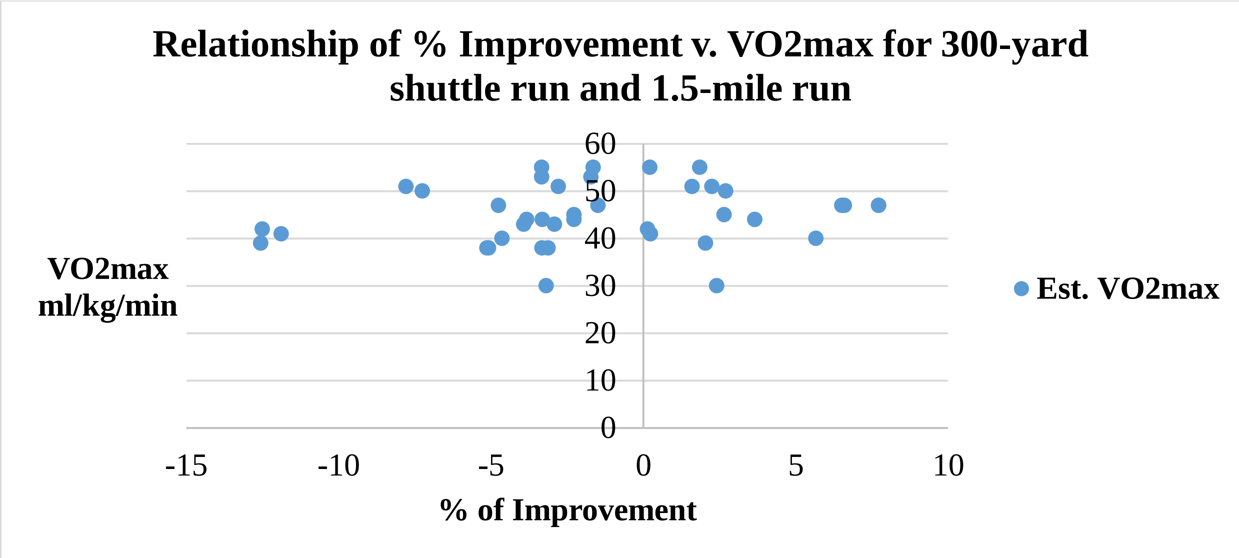

Figure 2.3.4: VO_{2max} plotted with percent of improvement for the 300-yard shuttle and 1.5-mile run performance times.

Comparisons in Figure 2.3.5 showed no significant difference for no warm-up (CC) and warm-up (IEC) for subject's performance time in the 300-yard shuttle (seconds); Conversely, in Figure 2.3.6 for the 1.5-mile (minutes) run showed significance difference from no warm-up (CC) (M= 13.108, SD=2.194) and warm-up (IEC) (M=12.683, SD=1.855); $t(19)=2.160$, $p=0.044$ for subject's performance time.

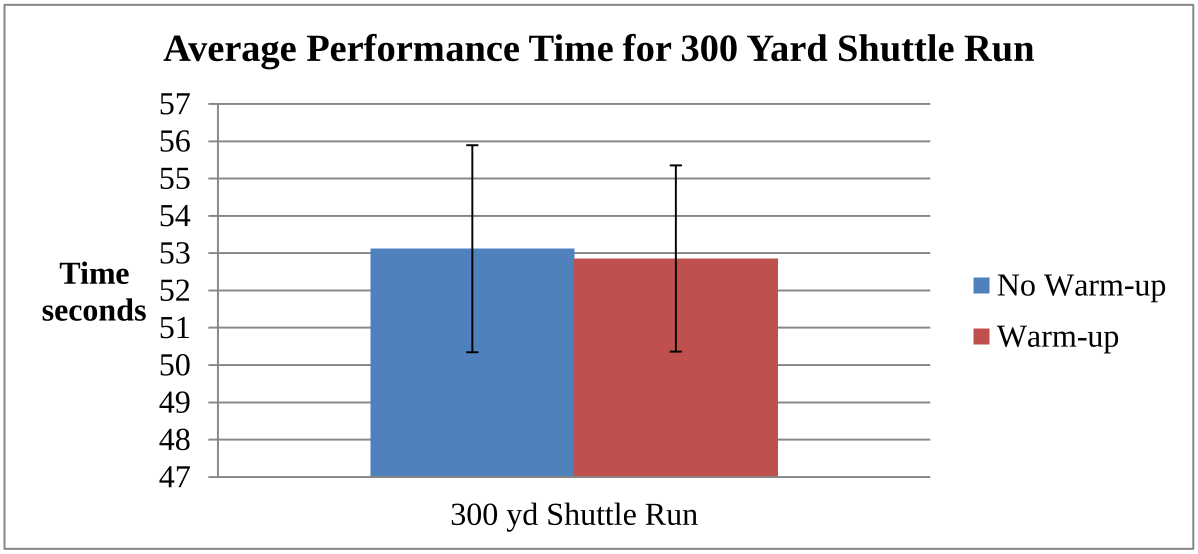

Figure 2.3.5: Average performance time for the 300 yard shuttle run comparing no warm-up (blue bar) and warm-up (red bar) with standard deviations and significance at $p \leq 0.05$*.

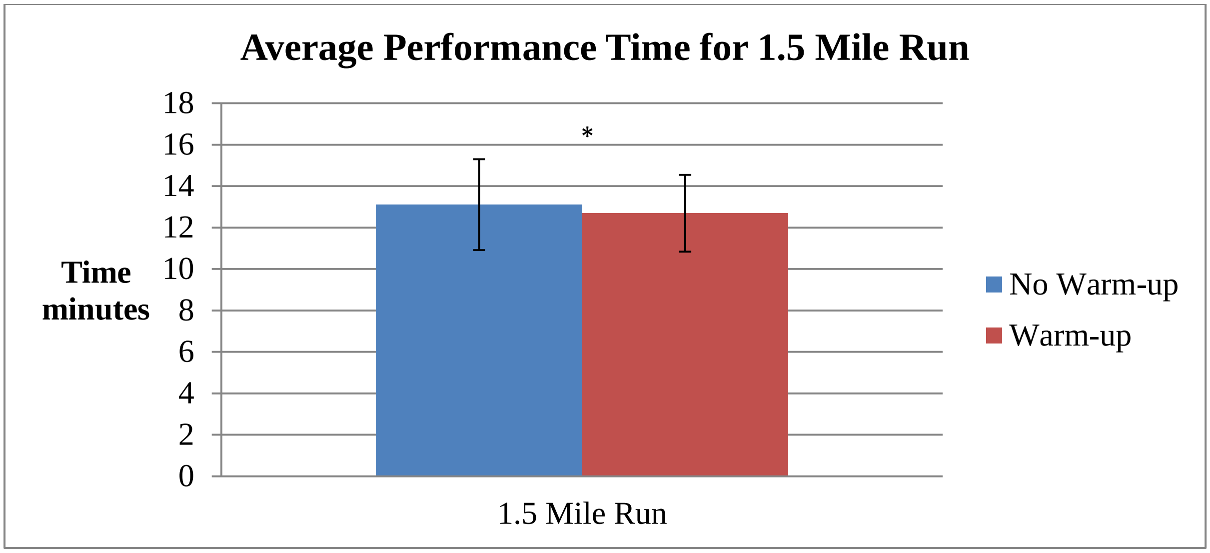

Figure 2.3.6: Average performance time for the 1.5-mile run comparing no warm-up (blue bar) and warm-up (red bar) with standard deviations and significance at $p \leq 0.05$*.

The recovery pulmonary function data for no warm-up (CC) compared to warm-up (IEC) for 300-yard shuttle and 1.5-mile run, are presented in Figure 2.3.7 and 2.3.8, respectfully. There was a significance difference for the FVC for no warm-up (CC) (M= 4.732, SD=0.626) and warm-up (IEC) (M=4.607, SD=0.631); t(19)=3.197, p=0.005 and FEV_1 for no warm-up (CC) (M= 3.960, SD=0.587) and warm-up (IEC) (M=3.860, SD=0.607); t(19)=3.050, p=0.007 for the 300 yard shuttle run at ten-minute interval (Figure 2.3.7) and in the FEV_1 for the 1.5-mile (minutes) run for the no warm-up (CC) (M= 3.852, SD=0.556) and warm-up (IEC) (M=3.722, SD=0.424); t(19)=2.160, p=0.017 at ten-minute recovery interval (Figure 2.3.8). No other paired sample of pulmonary functions values demonstrated significance.

Discussion. This is the first known study to investigate the effects of a breathing warm-up on recovery RPE breathing, run performance time, and recovery pulmonary function; therefore, the aim of this study was to evaluate the effects of a breathing warm-up using a combined inspiratory/expiratory (IEC) breathing warm-up on recovery rating of perceived exertion (RPE) breathing, performance time (300-yard shuttle and 1.5-mile run), and pulmonary function

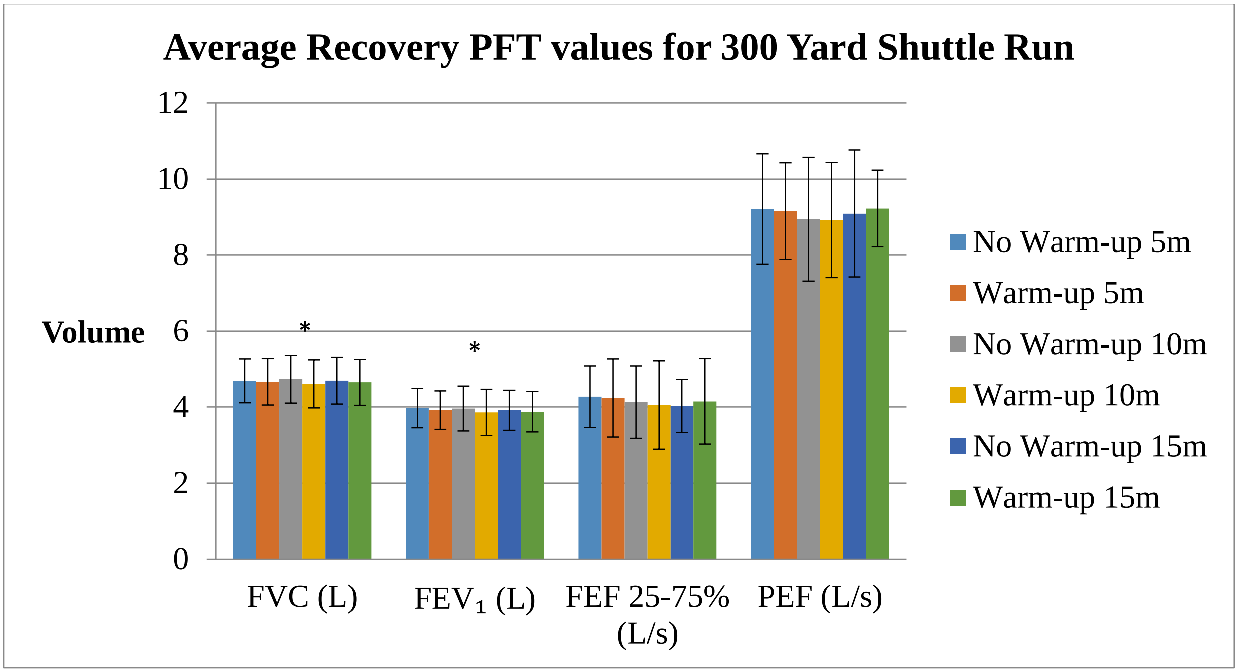

Figure 2.3.7: Average recovery PFT values for the 300 yard shuttle run comparing no warm-up at 5-minute (light blue bar), at 10-minutes (gray bar), at 15-minutes (dark blue bar), and warm-up at 5-minutes (orange bar), at 10-minutes (yellow bar), at 15-minutes (green bar), with standard deviations and significance at $p \leq 0.05$*.

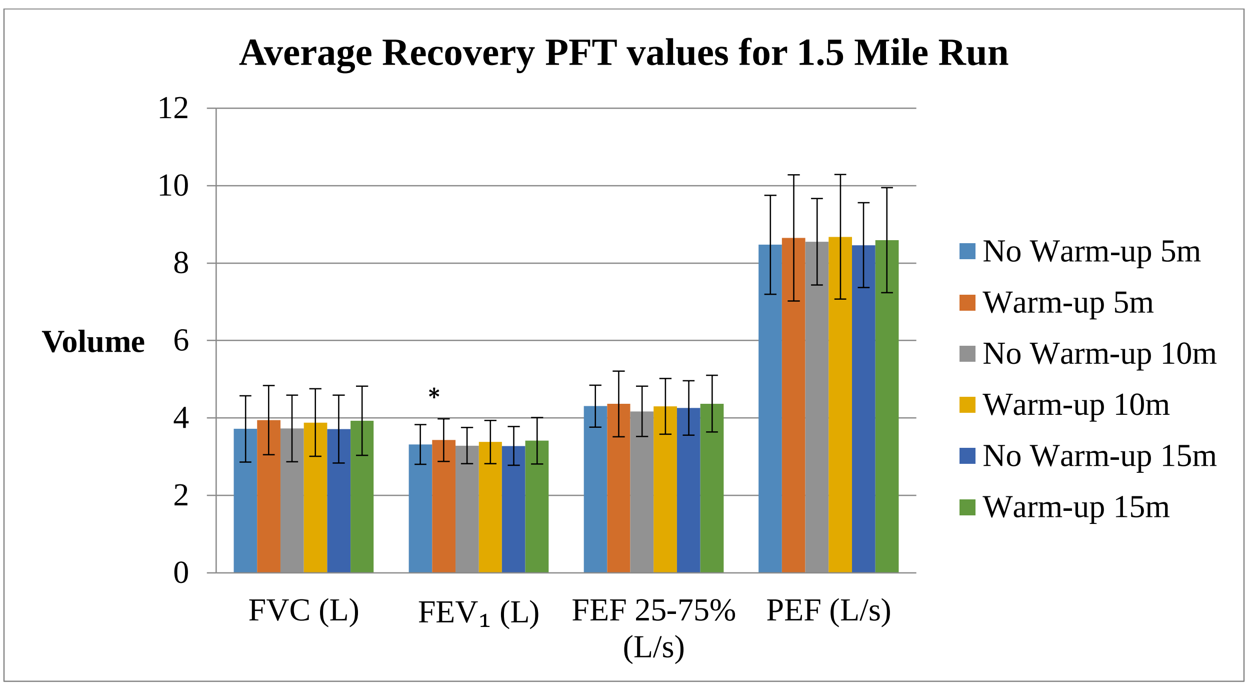

Figure 2.3.8: Average recovery PFT values for the 1.5 mile run comparing no warm-up at 5-minute (light blue bar), at 10-minutes (gray bar), at 15-minutes (dark blue bar), and warm-up at 5-minutes (orange bar), at 10-minutes (yellow bar), at 15-minutes (green bar), with standard deviations and significance at $p \leq 0.05$*.

measures (FVC, FEV_1, FEF 25-75%, and PEF). A secondary aim of this study was to determine if the subjects' performance improvement was affected by their fitness status (VO_{2max}). The data presented on run recovery RPE between no warm-up (CC) and warm-up (IEC) suggests there was significant difference for the 300 yard shuttle run at the immediate post run RPE, the 2-minute, and the 7-minute recovery RPE intervals and no significance differences demonstrated for the 1.5 mile run recovery RPE for both conditions. The performance time in the 1.5-mile run decreased by an average of 25 seconds (3.2% improvement) with warm-up (IEC) verses no warm-up (CC). The significant difference suggested for the FVC and FEV_1 at the ten-minute interval for 300-yard shuttle run and FEV_1 at the ten-minute interval for 1.5-mile run was not consistent with the stated hypothesis; as it was believed the warm-up (IEC) would increase pulmonary function. The remaining pulmonary function values lacked statistical significance. This study suggests no relationships between VO_{2max} and percentage improvement in the performance time of both runs.

The data on run recovery RPE suggest there were some time intervals (immediate post run, 2 and 7-minute) with significant differences between no warm-up (CC) and warm-up (IEC) for the 300 yard shuttle run but not the 1.5 mile run. These differences suggest the warm-up (IEC) actually increased the RPE in recovery. This outcome is possible because of the anaerobic nature of the run (300-yard shuttle) taxing the respiratory system maximally for such a short duration and compounded by the perception of the warm-up (IEC) just five-minutes earlier. Furthermore, individuals without a known history of difficulty breathing, as seen in this population of young healthy males, adjust to the metabolic demands such that they do not need the benefits provided by the breathing warm-up used in this study (Forster & Pan, 1988). As reviewed earlier, in healthy individuals, the dynamic capacity of the inspiratory and expiratory

muscles to force generate probably never limits the VE response to exercise (Guenette & Sheel, 2007), which is a reasonable explanation for lack of improvement seen across both runs (300-yard shuttle and 1.5-mile) of this population.

This study suggested a significant 3.2% improvement in performance time in the 1.5-mile run after the breathing warm-up (IEC). As indicated by de Bisschop et al. (1999) similar improvements were seen after a traditional warm-up protocol from their research on asthmatic children. Children improved their distance by 5% suggesting an enhancement in performance. Anecdotal observations in this study, found subjects perceived breathing less at the start of the 1.5-mile run after the warm-up (IEC); however their recovery RPE was unchanged when compared to the no warm-up (CC). How did these lower perceptions at the start of exercise contribute to the performance improvements; and if so, by what means? Research on time to exhaustion (performance) using loading and unloading of the respiratory muscles showed that loading via resistive devices produced a decrease in time to exhaustion and unloading with a PAV increased time to exhaustion averaging ±14-15% (Harms et al., 2000). These results suggest that increased performance (time to exhaustion) effect may be explained with reduced dyspnea perceptions secondary to reduced respiratory muscle work (Miller et al., 2006). Logically, performing a warm-up of the respiratory system directly before an exercise performance should reduce dyspnea perceptions, reduce respiratory muscle work, and produce improvements in performance. One possible mechanism of this process can be explained as priming the system as seen in traditional warm-up modalities reviewed earlier by many authors.

It was theorized that a breathing warm-up (IEC) would increase pulmonary function compared to no warm-up (CC). The findings suggest a statistically significant decrease in the FVC (2.7%) and FEV_1 (2.5%) at the ten-minute interval for the 300-yard shuttle run and FEV_1

(3.3%) at the ten-minute interval for 1.5-milerun for the warm-up. These results are similar to a study produced by Coast et al. (1999) indicating the effects of a maximal exercise trial (progressive maximal cycle ergometer test) in healthy subjects. A significant decrease in FVC (7%) was observed immediately following the exercise trial. The authors suggest data indicates pulmonary function and respiratory muscle strength may be altered following exercise; however, it is important to note, the present study's data should be viewed with caution as all significant values are less than 130 ml which is considered within the standards of repeatability (≤150 ml) for the FVC and FEV_1 measures (M. R. Miller et al., 2005).

In order to attempt to rule out fitness status (VO_{2max}) as a limit to performance improvements in this study, VO_{2max} was plotted against performance time changes. The data suggests a lack of a relationship between these variables.

In view of the limitations within this study, the following improvements should be considered: The subject populations consisting of healthy young males with no previous breathing challenges suggest a lack of significance improvement in perceived breathing for conditions (CC and IEC) and both runs. Subsequently, these subjects' perceptions of breathing during rest, activity, and recovery may be less sensitive because they tend to recover rather quickly from only having experienced breathing challenges during exercise at high intensity. Secondly, the use of recovery PFT measures to determine statistical differences in apparently healthy young males after exercise may not be sensitive enough to detect a direct effect of a breathing warm-up. The use of breath by breath analysis to track trends in total respiratory rate and tidal volumes during exercise; as well as exercise flow volume loops, may be a more precise measuring tools. Conversely, the breathing challenge created by the change in respiratory system structure (mouth piece, nose clips, and total mouth breathing) could possibly disguise any

positive change caused by the respiratory system warm-up. Lastly, the possibility that the number of subjects in this study could weaken the statistical reliability can never be discarded.

The possibilities of future study would be to consider diverse populations of subjects, those that have had breathing challenges before (asthmatics, chronic obstructive pulmonary disease, the elderly, and congestive heart failure) which may benefit from the breathing warm-up studied. The use more sensitive ways to measure the variables tested (breath by breath testing as one possible tool). And lastly, attention should be given to an evaluation of the breathing warm-up on more specific modalities (i.e. swimming, cycling, skiing, and/or 400 meter run) need to be considered.

Conclusion. In the exploration of new ways to enhance performance during activities where breathing may limit exercise, it was conceived that warming up the respiratory system before exercise could indeed improve performance. Findings from this study demonstrated a 3.2% improvement in performance time in a 1.5-mile run incorporating the warm-up treatment. Even though this improvement may not be viewed as a huge modification, when one considers the approximate cost of breathing on the system up to 14-16% of VO_{2max} and cardiac output in highly-trained individuals (Aaron et al., 1992; Harms, McClaran, et al., 1998) it becomes clear that any benefit can be appreciated. Miller et al. (2006) suggest that increase performances may be explained with reduced dyspnea perceptions secondary to reduced respiratory muscle work. The evidence presented in this study suggests a benefit to performing a warm-up of the respiratory system directly before an exercise performance; the mechanism of which may be explained by reduced dyspnea perceptions, reduced respiratory muscle work, thus producing improvements in performance. A secondary mechanism can be explain by priming the

respiratory system as seen in traditional warm-up modalities priming the skeletal and circulatory systems as reviewed earlier by many authors.

2.4 Experiment 4

Introduction. Many exercise physiologists believe that the respiratory system has little to no effect on limiting exercise performances in healthy individuals or athletes (A. McConnell, 2009), yet the respiratory system encounters several challenges during intense exercise. One example is the regulation of alveolar partial pressure of oxygen and carbon dioxide is achieved by a considerable increase in alveolar minute ventilation (V_E) often 20-times the resting value in humans. This large increase in V_E is achieved by the capacity of the respiratory muscles to not only generate forces to alveolar ventilation but also by limiting excessive physiological cost on the system during exercise (Guenette & Sheel, 2007). Another example challenging the respiratory system one must overcome is the ability of the bronchial (intra-thoracic) airways to maintain patency in order to allow the increase flow rate needed during active expiration often seen in intense exercise. During high intensity exercise, the bronchial airways occasionally do present a significant limitation to expiratory flow; therefore, causing dynamic hyperinflation, increased respiratory muscle work, and V_E limitation (Forster et al., 2012).

An often-overlooked ingredient to a possible limitation of the respiratory system is how the mechanical work of breathing has both sensory and metabolic repercussions. The perceived work of breathing contributing to how hard the exercise feels (sensory) and the demands the mechanical work of breathing places on the circulatory system for blood and oxygen to sustain muscle contraction (metabolic) (A. McConnell, 2009). It has been suggested that the metabolic and circulatory cost of a high mechanical work of breathing during maximal levels of V_E can amount to 8-10% of the VO_{2max} (maximal oxygen consumption) and cardiac output in the

untrained individual and up to 14-16% of VO_{2max} and cardiac output in highly-trained individuals (Aaron et al., 1992; Harms, McClaran, et al., 1998). It is further noted, with research on blood flow distribution, as the respiratory muscles are loaded, a reflex vasoconstriction is produced resulting in decreased blood flow to the exercising limb. Conversely, when the respiratory muscles were unloaded, a state of increased blood flow (dilation) existed in the exercising limb muscles (Harms, Wetter, et al., 1998). This change in limb blood flow indicates a competitive relationship between the muscles of locomotion and the muscles of respiration for limited cardiac output (Guenette & Sheel, 2007). These findings may well represent the respiratory system's challenge to sustain airway patency in the face of maximal or near maximal workloads, creating high V_E demands, competition for the available cardiac output with limb muscles, and variations in the respiratory muscles fatigue states.

Research on the value of pre-exercise warm-up has used only traditional training protocols and methods [high intensity interval (HIT), continuous low intensity (CLI), and continuous high intensity (CHI)] as the warm-up mode (McKenzie et al., 1994; Reiff et al., 1989; Schnall & Landau, 1980). Reiff et al. (1989) examined the effect of a prolonged warm-up period of exercise on subjects with exercise induced asthma (EIA) and found that both CLI and CHI warm-ups suggest a benefit (protection from EIA) for their subjects. McKensie et al. (1994) examined the protective effects of CLI warm-up and an interval warm-up (IW) exercise on post-exercise bronchoconstriction in athletes with EIA and their findings suggest the CLI protocol was significantly better than an IW protocol, but the IW was still significantly better than the control group. Schnall et al. (1980) examined the notion of bronchodilation produced by short periods of running (HIT) in subjects in which EIB had occurred after a standard exercise test. Their findings are suggestive that the use of repeated, short runs minimize the EIB and had a

bronchodilating effect on previous EIB. Their research also suggest that the data provides evidence to support asthmatics cope better with repeated, short duration activities (HIT) and a warm-up period may be beneficial in alleviating the effects of more prolonged exercise. These studies suggest the use of traditional training protocols as a pre-exercise warm-up providing subjects with a positive change in their pulmonary function and reduced EIB.

Another possible way to reduce the demand on the respiratory system's muscles and change pulmonary function is the use of a pre-exercise respiratory warm-up that involves non-traditional training methods. Non-traditional methods would use respiratory muscle training devices (inspiratory and expiratory muscle methods) to warm-up the respiratory muscles. Based on this author's literature review, there are not any studies researched on non-traditional warm-up methods to warm-up before exercise performance, but some studies have looked at the training effect of these types of training protocols (Griffiths & McConnell, 2007; Singh et al., 2011; Weiner et al., 1992) on pulmonary functions. Weiner et al. (1992) compared specific inspiratory muscle training versus sham training on inspiratory muscle strength and endurance in an adult bronchial asthma population. Observation of increases in inspiratory muscle strength and endurance was found as well as increases in the FVC (force vital capacity) and the FEV_1 (forced expiratory volume in one-second) when compared to the sham control group with six-months of training. Griffiths and McConnell (2006) investigated the effect of four-weeks of inspiratory muscle and/or expiratory muscle training and the subsequent effects of a six-week trial of combined inspiratory and/or expiratory muscle training in club-level oarsmen on rowing performance. The results of the study indicate an increase in inspiratory and expiratory muscle strength along with improvements in mean power rowing performance. Singh et al. (2011) examined the effect of upper-body resistance training and conventional deep breathing exercises

on pulmonary function in male smokers. The results indicated improvements in pulmonary function (FEV_1 and FEV_1/FVC). These studies suggest the use of non-traditional methods of training are an effective way to improve pulmonary function test, inspiratory and expiratory muscle strength, and exercise performance.

Since traditional training methods used as a pre-exercise warm-up demonstrate positive change in pulmonary function and performance, one may conclude a non-traditional method of training used as pre-exercise warm-up may demonstrate similar benefits. The concept of non-traditional methods used as a pre-exercise warm-up for the respiratory muscles to improve pulmonary function and exercise performance is a novel idea and worthy of investigation. As such, if a breathing warm-up can increase the mechanical advantage of the respiratory muscles prior to exercise, subjects may reduce the oxygen and cardiac output requirements during the initial stages for exercise. If oxygen consumption and cardiac output requirements of the respiratory muscles can be reduced during the initial stages of exercise performances than one might expect to appreciate a recovery benefit as well. Based on the results from experiment two in this study, the combined inspiratory and expiratory breathing condition (IEC from here on) demonstrated better results compared to either of the other conditions inspiratory (IC) and expiratory (EC) studied alone. As such, this experiment is an expanded examination of the IEC (warm-up) effect on performance, rating of perceived exertional breathing, and pulmonary function. The aim of this study is to evaluate the impact of a pre-exercise respiratory warm-up using non-traditional methods (combined inspiratory and expiratory muscle training modalities) on pulmonary function measures (FVC, FEV_1, FEF 25-75% PEF), performance time (300-yard shuttle and 1.5-mile run) and recovery rating of perceived exertion (RPE) breathing in asthmatic subjects. Thus, it is hypothesized the use of a pre-exercise respiratory warm-up (IEC) using non-

traditional methods (combined inspiratory and expiratory muscle training modalities) in subjects with asthma will increase pulmonary function measures (FVC, FEV_1, FEF 25-75%, PEF) and increase performance (reduced time to completion) achieved in a 300-yard shuttle and the 1.5-mile run as compared to the control condition (no warm-up). Secondary hypotheses are that fitness status of the subjects would not be related to decreases in performance time and subjects with asthma would rate their perceived exertion of breathing (RPE 1-10 point scale, Appendix 1.D.) level as lower during recovery from each run after the breathing warm-up.

Methods. Five subjects (1 male and 4 females) with diagnosed Asthma and prescribed recue medications aged 18 to 24 (mean 20.8-years) (Table 2.4.1) completed the four sessions of the study. Additionally, one subject enrolled but never completed any sessions due to injury and a second subject was initially screened but was not able to start because she never received her prescription for a recue medication; therefore their data were not incorporated into this experiment. Based on the results from experiment two in this study, the combined inspiratory and expiratory breathing condition/warm-up (IEC from here on) suggested better outcomes (most intense and increased PF) compared to either of the other conditions inspiratory (IC) and expiratory (EC) studied alone. As such, this experiment is an expanded examination of the IEC (warm-up) effect on performance, perceived breathing, and pulmonary functions. The study was conducted in a university-based kinesiology laboratory and gymnasium with the subject population drawn from volunteers of the university's athletic programs and student volunteers (convenience sample). Subjects were excluded based on health status from Physical Activity Readiness Questionnaire (ParQ) (smokers, pregnant females, and others that maybe at risk for exercise treatments were excluded). Subjects were informed of the potential risks and gave their written informed consent to participate prior to beginning the study and were encouraged to take

all prescribed medications consistently for the duration of the study. This study was approved by the University's Institutional Review Board for use of human subjects (see Appendix).

Table 2.4.1: Demographics for Experiment 4.

Gender	1 males and 4 females
Age	20.8±3.2
Height inches	65.1±6.9
Weight pounds	142.2±27.8
Body Mass Index	23.5±4.9
Percentage of Body fat	19.0±14.7
Estimated VO_{2max}	43.0±12.0

After completion of the informed consent, ParQ, and baseline data (height, weight, body fatness percent via bioelectrical impedance- Omron® HBF 306C, Omron, Corp., Schaumburg, IL) (Lukaski et al., 1986) for standardizing subjects, all subjects performed an initial resting series of (pre-medication) PFT followed by self-administration of their prescribed recue inhaler (albuterol sulfate x two puffs/inhales for all subjects). Subjects waited for five-minutes and performed a second series of (post-medication) PFTs followed by a randomly assigned resting (no-warm-up) control condition (CC) for five minutes or the IEC warm-up protocol for five-minutes. Subjects were instructed to perform the respiratory warm-up as follows: 1) Inhale deeply and forcefully to inspiratory capacity (IC) at a rapid flow on an incentive spirometer (IS device- measures inspiratory volume while visual giving feedback on high, medium, and low flow generated); 2) Hold the inhale (breath) for five-seconds; 3) Exhale forcefully at a rapid flow to residual volume (RV) through the Resistex® Mercury® Resistance Exercisers (RM) device with variable expiratory resistive load setting (set at 4 highest resistance) to RV. Once the five-minutes of no warm-up (CC) and warm-up (IEC) was completed, subjects rested for five-minutes and then performed a 300-yard shuttle run (50-yards each direction) (Cumming & Keynes, 1967) or a 1.5-mile run (running line for a consistent distance) (Larsen et al., 2002) for time in a gymnasium [subjects completed both runs and both the no warm-up (CC) and warm-up (IEC)].

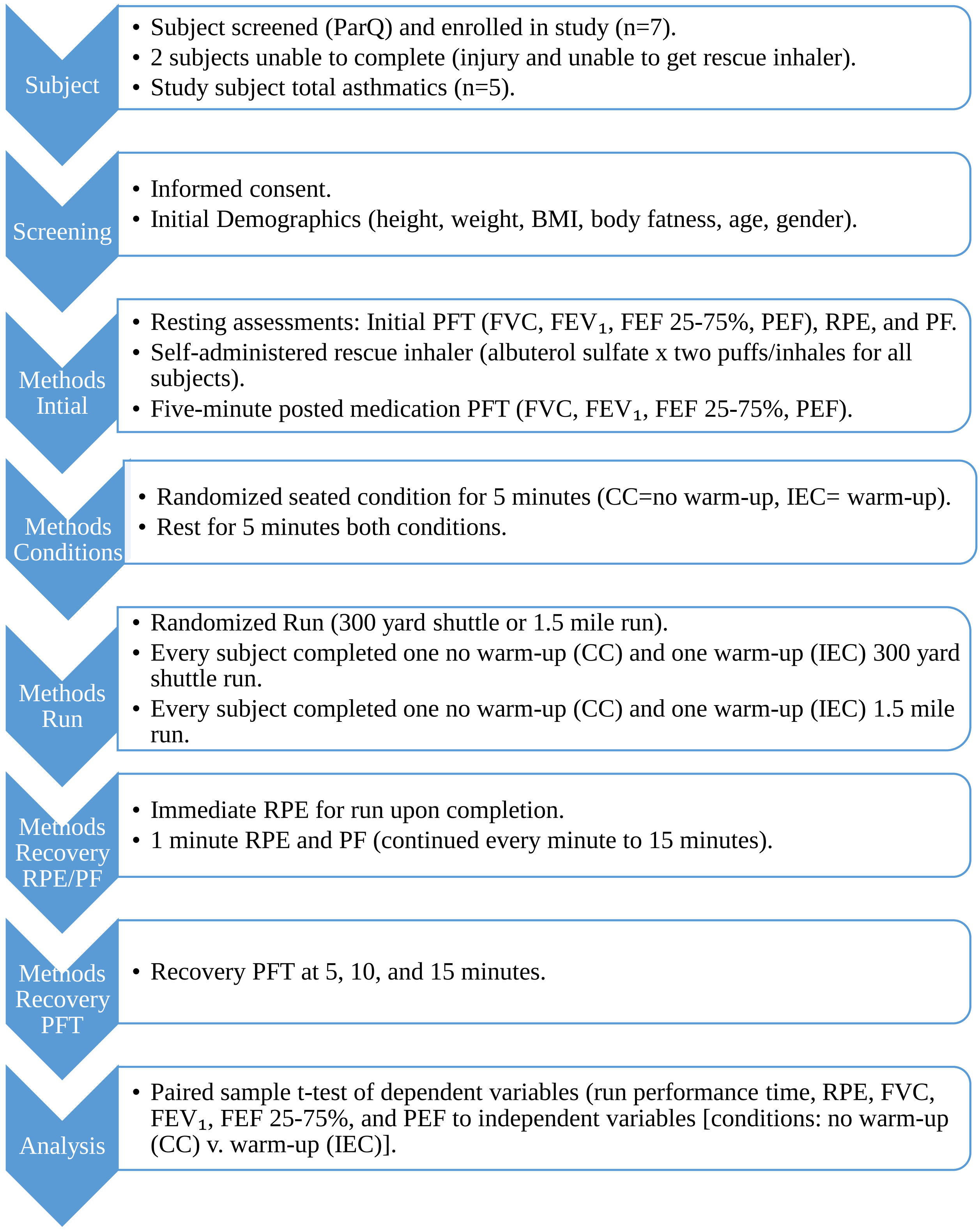

Figure 2.4.1: Flow chart of subjects, interventions and analysis.

Subjects were allowed limited self-directed stretching before runs and had access to the rescue inhaler throughout the study session. After completion of the runs, subjects returned to the kinesiology lab for recovery testing starting with PF and RPE for every minute for 15-minutes. At the 5, 10, and 15-minute intervals PFT data was collected. During each assessment interval, subjects were seated and a nose clipped was utilized. The test sequence required four days (two days for CC and two days for IEC) for completion. All subjects completed two 300-yard shuttle runs (one with warm-up, one without) and two 1.5-mile runs (one with warm-up, one without). Subjects were instructed and self-reported that they refrained from exercise, caffeine, and alcohol for 24-hours and had not eaten whole foods three hours before testing. Testing sessions were 24-hours apart. Fitness status was determined by predicting the subject's VO_{2max} from their best 1.5-mile run time (George et al., 1993; Larsen et al., 2002).

Pulmonary Function Measurements. Spirometry measures used were forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), forced expiratory flow 25-75% (FEF 25-75%) and peak expiratory flow (PEF). All pulmonary measurements were made with a Sensormedics Vmax® 29c Pulmonary Function/ Cardiopulmonary Exercise Testing Instrument. The instruments (flow and volume sensor) were calibrated daily following American Thoracic Society (ATS) accuracy standards (M. R. Miller et al., 2005). The laboratory atmospheric ranges were as follows: 1) temperature 68-74° F, 2) 60-70% relative humidity, and 3) barometric pressure 758-766 mmHg. Infection control was managed by instructing subjects to wash their hands upon entering the lab and each subject was assigned a sealed bag for their assigned Micrograd® Disposable Filter that was used only by them for each spirometry test. During all measurements, subjects were seated, their nose was clipped, and they were instructed on proper

testing technique by an experienced technician. All testing criteria followed the ATS evaluation standards (M. R. Miller et al., 2005).

Data Analysis. The dependent variables included performance times, RPE, FVC, FEV_1, FEF 25-75% and PEF and the independent variables are the conditions no warm-up (CC) and warm-up (IEC). Following experimentation, paired sample t-tests were calculated to compare no warm-up (CC) and warm-up (IEC). Additional, VO_{2max} was plotted against percent of improvement. The criterion for statistical significance of the correlations was set at $p \leq 0.05$. All statistical tests were performed on SPSS version 21.0 (Chicago, IL, U.S.A.).

Results. There was no significant difference in the 300 yard shuttle or the 1.5 mile runs for RPE recovery for both conditions [no warm-up (CC) v. warm-up (IEC)] as shown in Figure 2.4.2 and Figure 2.4.3, respectfully. However, the graph in Figure 2.4.3 demonstrates all recovery RPE values for the warm-up (IEC) are less than the values for no warm-up (CC) for the 1.5 mile run. The data in Figure 2.4.4 suggest no relationship between VO_{2max} and the percentage of improvement in performance for the 300-yard shuttle and 1.5-mile run.

Comparisons for no warm-up (CC) and warm-up (IEC) for subject's performance time in the 300-yard shuttle (seconds) in Figure 2.4.5 and the 1.5-mile (minutes) run in Figure 2.4.6 showed no significant difference for both runs and conditions (CC and IEC).

The recovery pulmonary function data for no warm-up (CC) compared to warm-up (IEC) for 300-yard shuttle and 1.5-mile run, are presented in Table 2.4.7 and Table 2.4.8, respectfully. There was a significant difference between the FEV_1 at five-minute recovery interval FEV_1 for no warm-up (CC) (M= 3.312, SD=0.513) and warm-up (IEC) (M=3.428, SD=0.549); t (4) = -3.833, p=0.019 for the 1.5-mile run (Table 2.4.7). No other paired sample of pulmonary

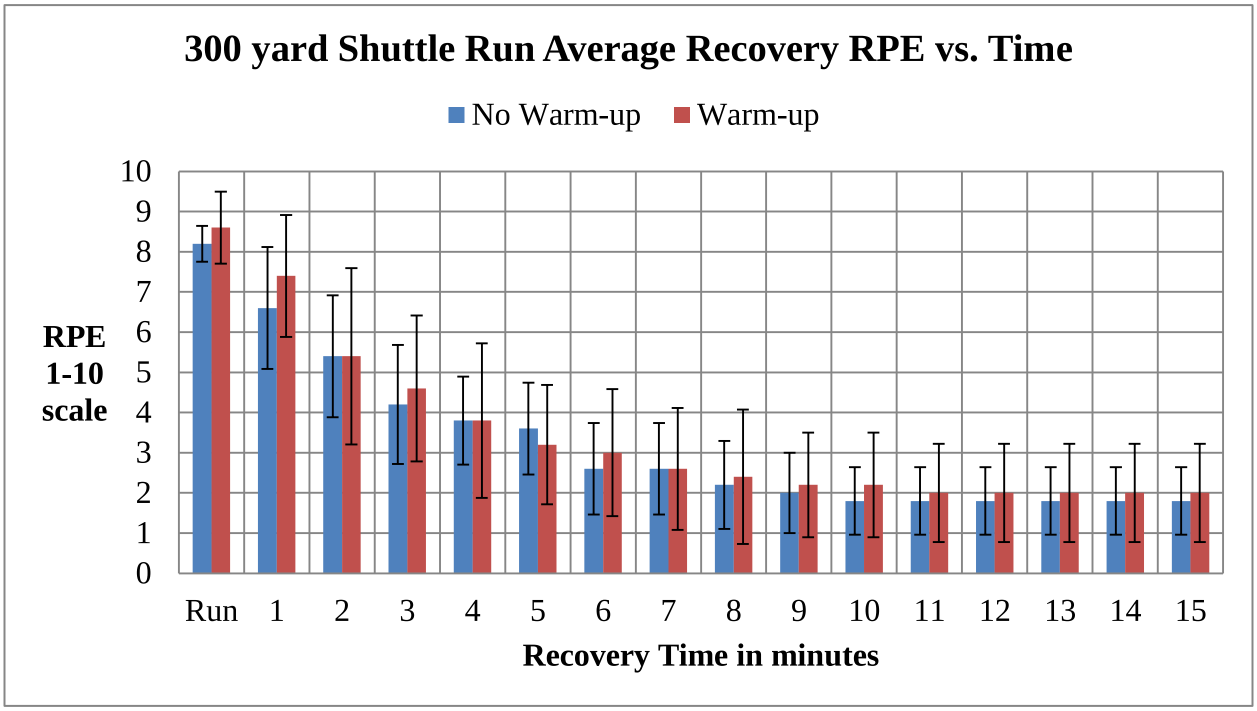

Figure 2.4.2: Average recovery RPE for the 300-yard shuttle run comparing no warm-up (blue bar) and warm-up (red bar) with standard deviations and significance at $p \leq 0.05$*.

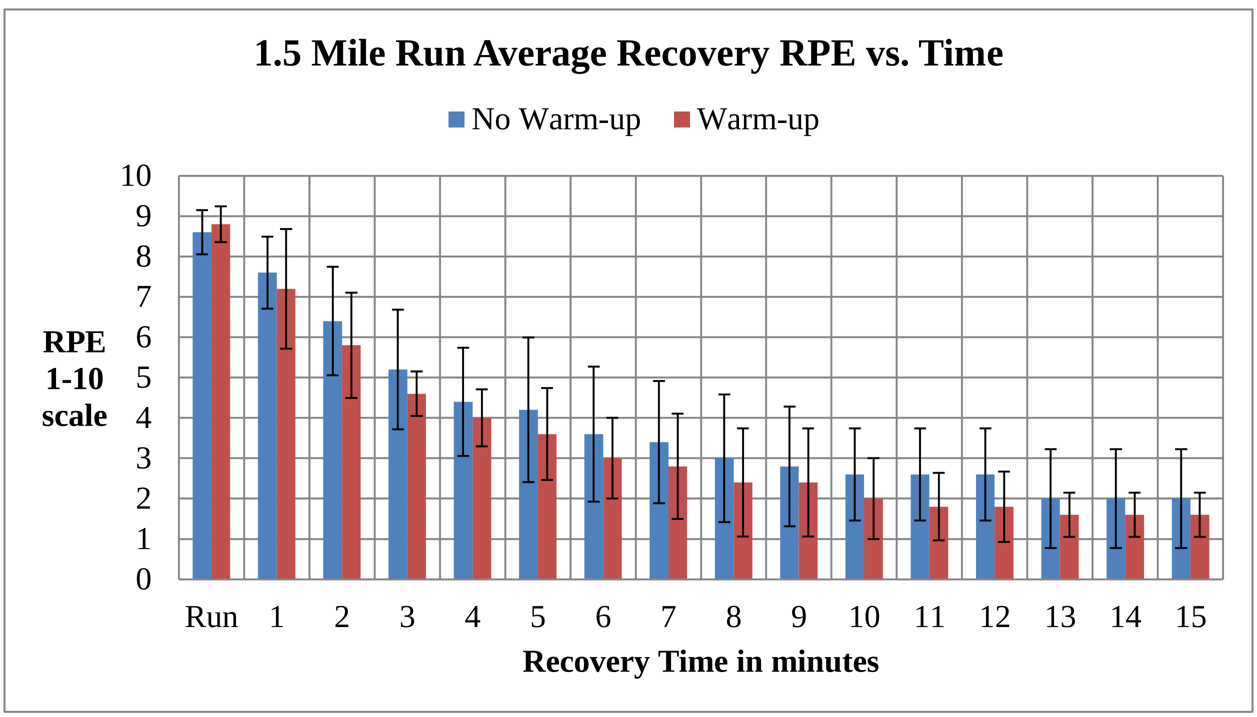

Figure 2.4.3: Average recovery RPE for the 1.5-mile run comparing no warm-up (blue bar) and warm-up (red bar) with standard deviations and significance at $p \leq 0.05$*.

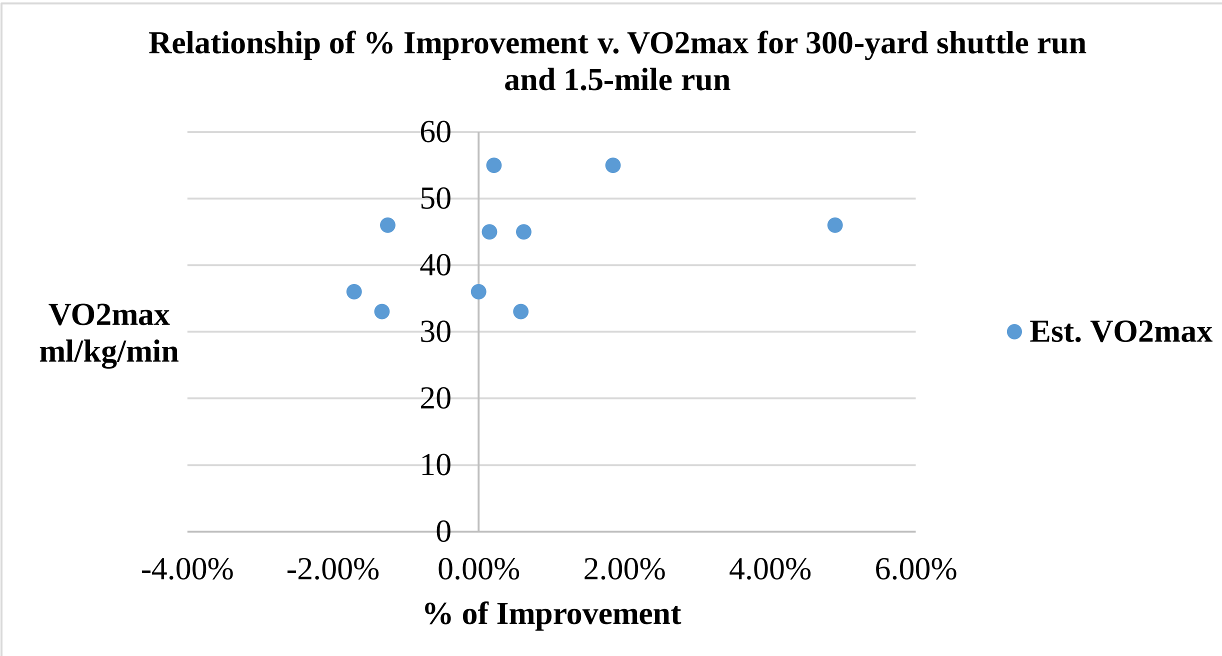

Figure 2.4.4: VO2max plotted with percent of improvement for the 300-yard shuttle and 1.5-mile run performance times.

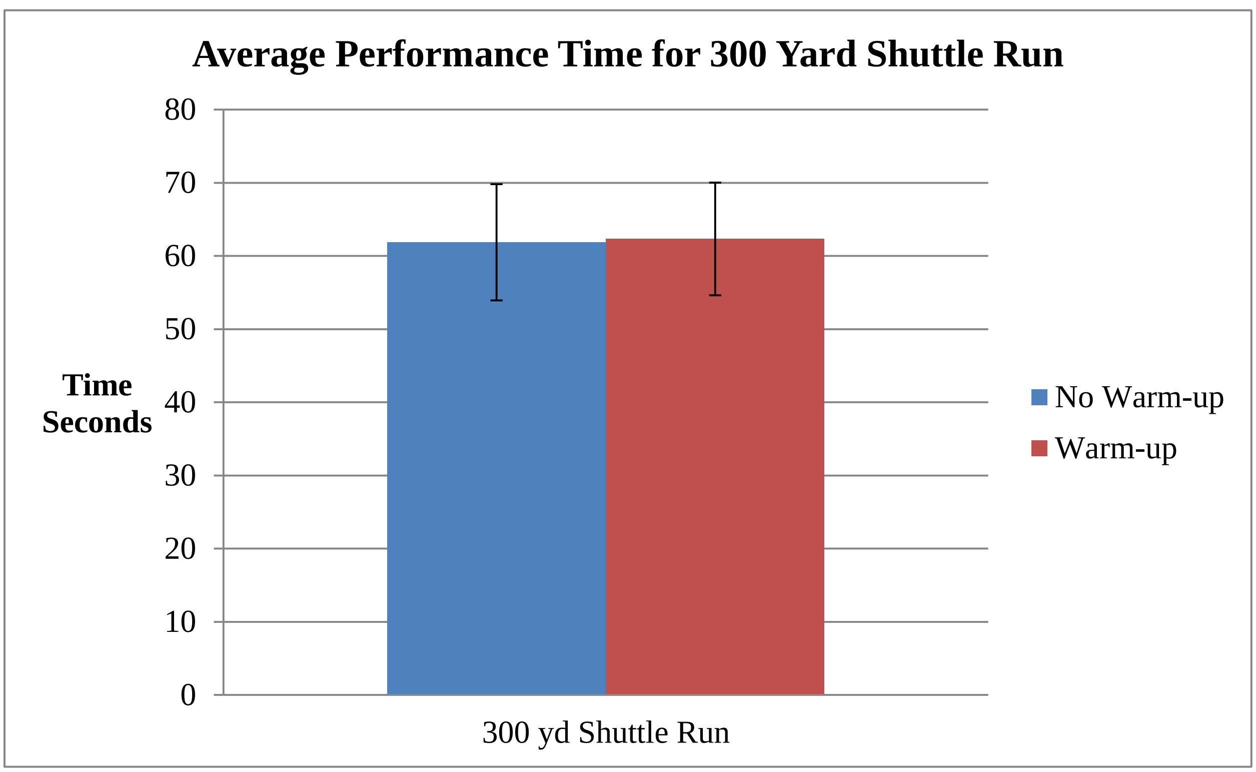

Figure 2.4.5: Average performance time for the 300 yard shuttle run comparing no warm-up (blue bar) and warm-up (red bar) with standard deviations and significance at $p \leq 0.05$*.

Figure 2.4.6: Average performance time for the 1.5-mile run comparing no warm-up (blue bar) and warm-up (red bar) with standard deviations and significance at $p \leq 0.05$*.

functions values showed significance for any recovery time interval or pulmonary function value for both runs.

Discussion. This is the first known study to investigate the effects of a breathing warm-up on recovery RPE for breathing, run performance time, and recovery pulmonary functions in subjects with asthma; therefore the aim of this study was to evaluate the effects of breathing warm-up (IEC) on recovery rating of perceived exertion (RPE) breathing, performance time (300-yard shuttle and 1.5-mile run), and pulmonary function measures (FVC, FEV_1, FEF 25-50%, and PEF) on subjects with asthma. A secondary aim to this study was to determine if subjects' performance time improvements were affected by their fitness status (VO_{2max}). The data on run recovery RPE between no warm-up (CC) and warm-up (IEC) suggest there is no

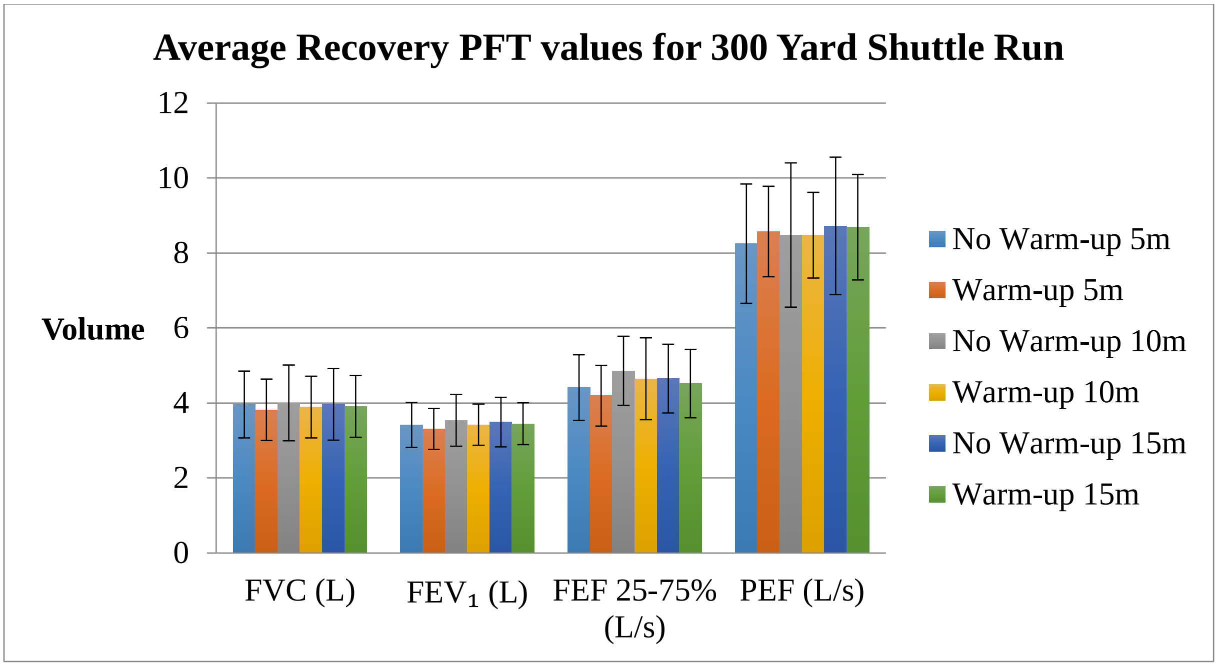

Figure 2.3.7: Average for recovery PFT values for the 300 yard shuttle run comparing no warm-up at 5-minute (light blue bar), at 10-minutes (gray bar), at 15-minutes (dark blue bar), and warm-up at 5-minutes (orange bar), at 10-minutes (yellow bar), at 15-minutes (green bar), with standard deviations and significance at $p \leq 0.05$*.

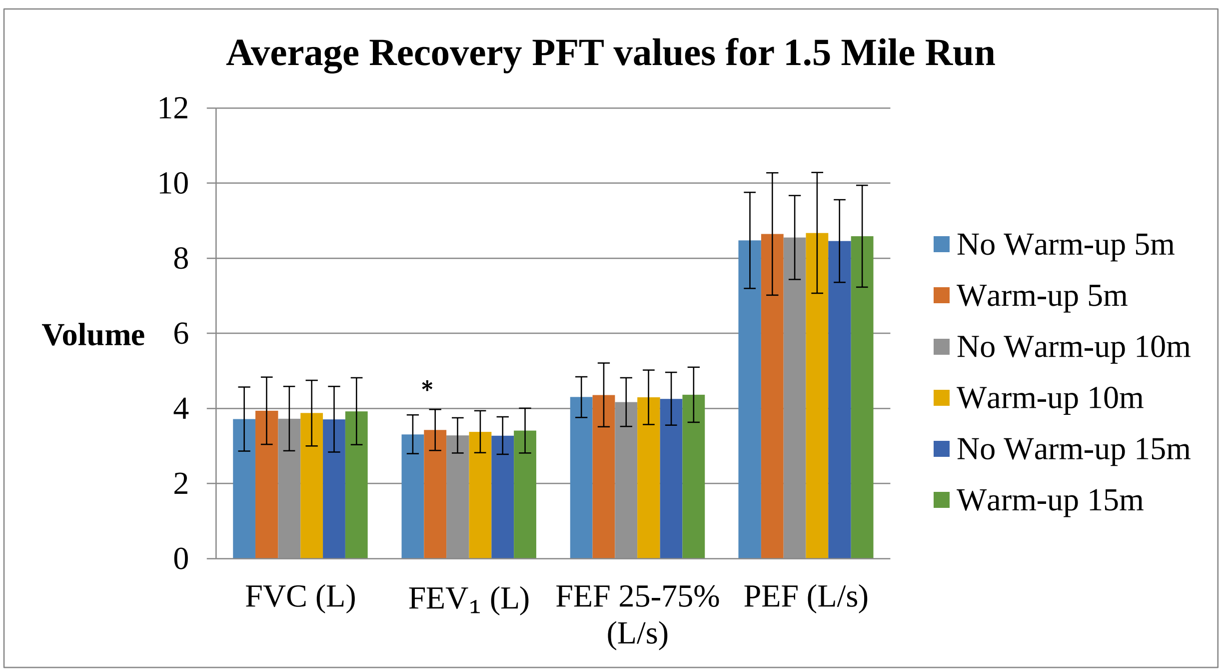

Figure 2.4.8: Average recovery PFT values for the 1.5 mile run comparing no warm-up at 5-minute (light blue bar), at 10-minutes (gray bar), at 15-minutes (dark blue bar), and warm-up at 5-minutes (orange bar), at 10-minutes (yellow bar), at 15-minutes (green bar), with standard deviations and significance at $p \leq 0.05$*.

significance difference for both runs. However, the graph (Figure 2.4.3) for no warm-up (CC) and warm-up (IEC) from the 1.5-mile run suggests lower recovery RPE values for all intervals after the warm-up (IEC). There were no statistical differences in performance times as it is related both conditions (CC v. IEC) and both runs. There is significant difference indicated for FEV_1 at the five-minute interval for the 1.5 -mile run which was consistent with the stated hypotheses; as it was believed that the respiratory warm-up would increase pulmonary functions. The remaining pulmonary function values lack statistical significance for the asthmatic subjects. This study suggests no relationships between the subjects' VO_{2max} and their percentage of improvement in performance of both runs.

The data on run recovery RPE between no warm-up (CC) and warm-up (IEC) suggest no significant difference for both runs; therefore, there is a possibility these asthmatic subjects would rate their perceived breathing as higher because of the anaerobic nature of the run (300-yard shuttle) taxing the respiratory system maximally in such a short time frame compounded by the perception of the warm-up just five minutes earlier. Anecdotally, it was the investigator's observation that asthmatic subjects had a heighten sense of perceived breathing and often their RPE for breathing at the start of the test session was above that seen from the subjects (young healthy males) studied in experiment three of this study. Consequently, Asthmatic subjects seem more sensitive to their perception of breathing during rest, activity, and recovery as most experience breathing challenges daily and with any exercise. Even more so, there may be an expectation that asthmatics' breathing will recover slower; hence, the value of a respiratory warm-up (IEC) as suggested by the lower recovery RPE intervals for 1.5-mile run after such a warm-up. This type of outcome can be viewed as the warm-up did benefit the subjects breathing perception during recovery.

There was no significant difference in performance times between no warm-up (CC) and warm-up (IEC) for both runs, which can be attributed to the small sample of subjects tested (n=5). However, research by Schnall et al. (1980) and Mickleborough et al. (2007) studied small numbers in subjects, (n=6 and n=8, respectfully) and suggested statistical significance in their procedures and protocols. Thus, it is believed that a larger sample size would strengthen the statistical analysis and power of this study. Likewise, this subject population was made up of one non-athlete (apparently healthy young female) and four young athletes across three collegiate sports (one male cross country, two female softball players, and a female soccer player). The data point scatter seen in Figure 2.4.4 suggests a lack of relationship between performance improvements and fitness status (VO_{2max}). This inability to show fitness levels to be a limit to performance improvements could be due to the fact that the majority of these asthmatics subjects are well conditioning athletes, which will mask any differences that would be manifested by a more dissimilar population.

Recovery pulmonary functions data indicates there was significant difference for the FEV_1 at five-minute interval for the 1.5-mile run with no warm-up (CC) compared to warm-up (IEC). In relation to this study, the warm-up produced a higher FEV_1 (3.4%) which agrees with the hypothesis that the warm-up would increase pulmonary functions, similar to Mickleborough et al. (2007) which investigated a high-intensity interval warm-up protocol (WU) and combined medication dosing with albuterol sulfate (IH) the exact medication subjects used in this study. Their results suggest both IH and WU+IH interventions produced significant bronchodilation with mean maximum percentage change of post-exercise FEV_1 following the IH and the WU+IH, both demonstrated an increase of +8.9% and +15.2%, respectfully. However, the findings of the present study should be viewed with caution as the significant value is less than

120 ml which is within the standard of repeatability (≤150 ml) for the FEV_1 values (M. R. Miller et al., 2005). The outcome of this study suggests that statistical significance does not necessarily relate to practical significance.

Considering the limitations with in this study, the following should be pondered: Anecdotally, the majority of these subjects (athletes) stated to the coldness (68-74° F) of the gymnasium area (where the runs took place) to be difficult on their breathing as compared to their natural exercise environment (outdoors). Considering the effect of exercise on the airway, it is conceivable these subjects may have experienced some dehydration of the airway surface, leading to an increase in airway osmolarity. This increased osmolarity creates inflammation, therefore releasing mediators of prostaglandins, leukotrienes, and histamine from mast cells causing bronchoconstriction (Anderson & Holzer, 2000). However, these subjects did not experience the severe dehydration just described, the outcome is worth mentioning that all the described subjects participate in outdoor sports in Louisiana, (high humidity and high temperatures) and may have perceived their activity differently if tested outdoors. Secondly, the PFT measures used to determine significant differences in apparently healthy young asthmatics may not be sensitive enough to detect the effect of a breathing warm-up (IEC). The use of breath by breath analysis to track trends in total respiratory rate and tidal volumes during exercise as well as exercise flow volume loops may be a more precise measurement tool. Moreover, the breathing challenge due to the change the respiratory system structure (mouth piece, nose clips, and total mouth breathing) could possibly disguise any change caused by a respiratory system warm-up. Therefore, asthmatic subjects may be more sensitive to this type of change in respiratory system structure. It was this investigator’s objective not to alter the respiratory system

structure, in order construct the runs as naturally occurring as possible to promote real life exercise situations.

Areas for future study would be to consider diverse populations of subjects, for example, individuals that have had breathing challenges before (further study of asthmatics, chronic obstructive pulmonary disease, the elderly, and congestive heart failure) that may benefit from the breathing warm-up (IEC) studied. A possible consideration is to use more sensitive ways to measure the variables tested (breath by breath testing as one possible tool). Also, the exposure to natural environmental conditions should be considered to fit the subjects' activity profile. And lastly, a consideration should be made to evaluate the breathing warm-up on more specific modalities (i.e. swimming, cycling, skiing, and/or 400-meter run).

Conclusion. In the exploration of new ways to enhance performance during activities where breathing may limit exercise, it was conceived that warming up the respiratory system before exercise could indeed improve performance for apparently healthy and asthmatic individuals alike. This study demonstrates after a breathing warm-up, asthmatic subjects had lower perceived breathing during recovery after the 1.5-mile performance run. Furthermore, even though there is no statistical significance, this observation supports the belief that a breathing warm-up would benefit asthmatic subjects. Miller et al. (2006) suggest that increase in performance may be explained with reduced dyspnea perceptions secondary to reduced respiratory muscle work. With this idea in mind, it makes sense that performing a warm-up of the respiratory system directly before an exercise performance would reduce dyspnea perceptions, reduce respiratory muscle work, and thus, produce improvements in exercise performance in asthmatics. This mechanism can be explained as priming the system as seen in traditional warm-up modalities that was reviewed earlier by many authors. This is a population

that already has increased sensitivity of their perception of breathing during rest, activity, and recovery as most asthmatics experience breathing challenges daily and with any exercise. Therefore, the importance of a breathing warm-up for asthmatics cannot be diminished.

CHAPTER 3. CONCLUSION

The current study's results suggest a breathing warm-up before an exercise performance may be beneficial in young healthy males and asthmatic subjects (male and female). Furthermore, it was this study's primary objective to discover new ways to enhance performance during activities where breathing may limit exercise; therefore, it was conceived that warming up the respiratory system before exercise could indeed improve the exercise performance of a healthy individual and asthmatics.

Experiment three of this study suggests an aerobic performance run improvement of 3.2% when healthy male subjects performed a breathing warm-up prior to their performance. With the approximate cost of breathing on the body's metabolic system up to 14-16% of VO_{2max} and the cardiac output in highly trained individuals (Aaron et al., 1992; Harms, McClaran, et al., 1998), a 3.2% improvement in performance is a realistic outcome from a breathing warm-up. As Miller et al. (2006) suggest, increases in performance may be explained with reduced dyspnea perceptions secondary to reduced respiratory muscle work. Most subjects stated they perceived breathing as easier during the early stages of the 1.5 mile run. Therefore, a case can be made that performing a breathing warm-up before an exercise performance may reduce dyspnea perceptions, reduce respiratory muscle work, and thus, produce improvements in exercise performance. Traditional warm-up protocols prepare the skeletal muscles and cardiovascular system for future exercise performances; therefore, it can be viewed that this type of breathing warm-up also prepares the respiratory muscles in the same way by priming the system for optimal performance.

The results in experiment four of this study seem to be supported by the implications of Miller et al. (2006) that increased performance may be explained with reduced dyspnea

perceptions secondary to reduced respiratory muscle work. The graphic results suggest that when asthmatics used a breathing warm-up before an aerobic performance run, they experienced lower perceived breathing during recovery, though no performance improvements were noted with the breathing warm-up, they seemed to recover faster. In this study population, there is already an existence of increased sensitivity to breathing during rest, activity, and recovery, as these individuals often rated their resting and exercise RPE higher than the young healthy males tested in experiment three of this study. Thus, it is logical that performing a warm-up of the respiratory system directly before an exercise performance could reduce dyspnea perceptions, reduce respiratory muscle work, and produce improvements in exercise performance. As concluded with young healthy males and the use of traditional warm-ups, as studied and reviewed earlier, priming the systems before performance produces benefits as it relates to the outcome of exercise performance; therefore, the importance of the results of this experiment on asthmatics should not be disregarded.

The scientific literature on this topic is non-existent, as many exercise physiologists believe that the respiratory system has little to no effect on limiting exercise performance in healthy individuals or athletes (A. McConnell, 2009). I suggest this view is inaccurate because the regulation of alveolar partial pressure of oxygen (O_2) and carbon dioxide is achieved by a considerable increase in alveolar ventilation, minute ventilation (VE), often 20 times the resting value in humans. This respiratory system challenge is met only by the capacity of the respiratory muscles to not only generate force to alveolar ventilate but also limiting excessive physiological cost on the system during exercise (Guenette & Sheel, 2007). This is supported by research that indicates the approximate cost of breathing on the body's metabolic system up to 14-16% of VO_{2max} and the cardiac output in highly trained individuals (Aaron et al., 1992; Harms,

McClaran, et al., 1998). Thus, is it possible to decrease the physiological cost of breathing during exercise performance and if so, how could such a decrease be accomplished?

After conducting this study, it is suggested that the breathing warm-up used reduced breathing perceptions during and following exercise; thereby, reducing the physiologic cost of breathing as seen in both subject populations. The suggested mechanism in the young healthy males was reflected in their statements perceiving breathing as easier during the early stages of the aerobic run, which ultimately produced exercise performance improvements suggested. The asthmatic subjects appreciated their benefit during the recovery from the aerobic run, with reduced perceptions of breathing following the breathing warm-up, though they didn't see improvements in performance they seemed to recover faster.

The clinical significance of a faster recovery and reduced breathing perceptions from a breathing warm-up can be far reaching for individuals with breathing challenges with daily activities such as chronic obstructive pulmonary disease (COPD) and congestive heart failure (CHF) patients. These individuals often cannot meet the metabolic demand of activities of daily living or exercise as performed in pulmonary/cardiac rehabilitation because of high work of breathing and significantly deconditioning. If a breathing warm-up can help this population recover faster and experience reduced dyspnea perceptions, they should be able to exercise longer with fewer interruptions of rehabilitation exercises, consequently improve exercise training and conditioning efficiency. Therefore, future investigations using a breathing warm-up should study these populations as well as the deconditioned elderly. Additionally, the exploration of more sensitive ways to measure the variables tested (breath by breath testing as one possible tool) during the performance and recovery to enhance data collection. In athletic populations, investigations should consider the conditions suitable to the subjects' natural performance

environment, and lastly, the evaluation of the breathing warm-up on more specific modalities of performances (i.e. swimming, cycling, skiing, and/or 400-meter run), as well as, recovery from these performances.

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APPENDIX: RELEVANT EXTRA DOCUMENTS

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Robert Mathews, Chair
131 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.6792
irb@lsu.edu | lsu.edu/irb

TO:	Arnold Nelson Kinesiology
FROM:	Robert C. Mathews Chair, Institutional Review Board
DATE:	April 15, 2013
RE:	IRB# 3382
TITLE:	Role of Pulmonary Function during Exercise Recovery

New Protocol/Modification/Continuation: New Protocol

Review type: Full X Expedited ___ **Review date:** 4/12/2013

Risk Factor: Minimal ______ Uncertain X Greater Than Minimal ______

Approved* X **Disapproved** ______

Approval Date: 4/12/2013 **Approval Expiration Date:** 4/11/2014

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 30

Protocol Matches Scope of Work in Grant proposal: (if applicable) ______

***Approval Note: Your study is not to begin until your Certificate of Confidentiality is approved and on file with the LSU-BR Institutional Review Board**

By: Robert C. Mathews, Chairman Robert C. Mathews

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.fas.lsu.edu/osp/irb*

Project Report and Continuation Application

(Complete and return to IRB, 130 David Boyd Hall.
Direct questions to IRB Chairman Robert Mathews 578-8692.)

Institutional Review Board
Dr. Robert Mathews, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

IRB#: 3382 **Your Current Approval Expires On:** 4/11/2014

Review type: Full **Risk Factor:** Uncertain **Date Sent: 2/4/2014**

PI: Arnold Nelson **Dept:** Kinesiology **Phone:** Aug-14

Student/Co-Investigator: Dennis Guillot

Project Title: Role of Pulmonary Function during Exercise Recovery

Number of Subjects Authorized: 30

Please read the entire application. **Missing information will delay approval!**

I. PROJECT FUNDED BY: LSU proposal #:

II. PROJECT STATUS: Check the appropriate blank(s); and complete the following:

X 1. **Active**, subject **enrollment continuing**; # subjects enrolled: 10
___ 2. **Active**, subject **enrollment complete**; # subjects enrolled: ___
___ 3. **Active**, subject **enrollment complete**; work with subjects continues.
___ 4. **Active, work with subjects complete**; data analysis in progress.
___ 5. Project **start postponed**
___ 6. **Project complete**; end date __/__/__
___ 7. **Project cancelled**: no human subjects used.

III. PROTOCOL: (Check one)

X Protocol continues as previously approved
___ Changes are requested*

- *List (on separate sheet) any changes to approved protocol.*

IV. UNEXPECTED PROBLEMS: (did anything occur that increased risks to participants):

- State number of events since study inception: 0 since last report: 0
- If such events occurred, describe them and how they affect risks in your study, in an attached report.
- Have there been any **previously unreported** events? Y/N N ?
  (If YES, attach report describing event and any corrective action).

V. CONSENT FORM AND RISK/BENEFIT RATIO:

Does new knowledge or adverse events change the risk/benefit ratio? Y/N N ;
Is a corresponding change in the consent form needed? Y/N N

VI. ATTACH A BRIEF, FACTUAL SUMMARY of project progress/results to show continued participation of subjects is justified; or to provide a final report on project findings.

VII. ATTACH CURRENT CONSENT FORM (only if subject enrollment is continuing); and check the appropriate blank:

X 1. Form is unchanged since last approved
___ 2. Approval of revision requested herewith: (identify changes)

Signature of Principal Investigator: [signature] **Date:** 2-10-2014

IRB Action:	√ Continuation approved; **Approval Expires:** 2/13/15
	___ Disapproved
	___ File closed
Signed [signature]	Date 2/14/14

Form date: April 16, 2008

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Robert Mathews, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Arnold Nelson
Kinesiology

FROM: Robert C. Mathews
Chair, Institutional Review Board

DATE: March 13, 2014
RE: **IRB#** 3470

TITLE: The Effects of Three Respiratory Muscle Warm-ups on Rate of Perceived Exertion and Peak Expiratory Flow Rate

New Protocol/Modification/Continuation: New Protocol

Review type: Full ___ Expedited X **Review date:** 3/14/2014

Risk Factor: Minimal X Uncertain ______ Greater Than Minimal______

Approved X **Disapproved**__________

Approval Date: 3/14/2014 **Approval Expiration Date:** 3/13/2015

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 25

Protocol Matches Scope of Work in Grant proposal: (if applicable)______

By: Robert C. Mathews, Chairman Robt C Mathews

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Arnold Nelson
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: July 1, 2014
RE: IRB# 3501

TITLE: The Effects of Respiratory Muscle Warm-up on Exercise Performance and Pulmonary Functions in EIB and Non-EIB Subjects

New Protocol/Modification/Continuation: New Protocol

Review type: Full _X_ Expedited ___ **Review date:** 6/13/2014

Risk Factor: Minimal ____ Uncertain _X_ Greater Than Minimal ____

Approved _X_ **Disapproved** ____

Approval Date: 6/13/2014 **Approval Expiration Date:** 6/12/2015

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 40

LSU Proposal Number (if applicable): ____

Protocol Matches Scope of Work in Grant proposal: (if applicable)____

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
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Rate of Perceived Exertion Scale	
1	Nothing
2	Very Easy
3	Easy
4	Comfortable
5	Somewhat Difficult
6	Difficult
7	Hard
8	Very Hard
9	Extremely Hard
10	Exhausted

VITA

Dennis Jonathan Guillot, a native of Raceland, Louisiana, received his bachelor's degree at the University of Louisiana-Lafayette in 1994 and quickly began a master's degree and receiving his master's degree in 1996 from the of Department of Kinesiology at Louisiana State University. In 1999, he became Assistant Professor at Nicholls State in Thibodaux, Louisiana, and also worked in local Hospitals as a Respiratory Therapist. As his interest to in teaching at a university grew, he made the decision to enter graduate school in the Department of Kinesiology at Louisiana State University. He will receive his in doctorate degree in May 2015 and plans to continue to work at Nicholls State upon graduation.