ABSTRACT

THE EFFECT OF INSPIRATORY MUSCLE STRENGTH TRAINING ON VENTILATION AND DYSPNEA DURING SIMULTANEOUS EXERCISE AND SPEECH

By: Jamie Eileen Luketic

The demands placed on respiration during simultaneous exercise and speech creates the potential to increase dyspnea and the time for recovery. The purpose of this study was to determine the effect of an inspiratory muscle strength training (IMST) program on these two functionally limiting factors during simultaneous exercise and speech. Ten healthy adults were randomly assigned to an Experimental and Sham training program. MIP was used as an indirect measure of inspiratory muscle strength and measured at baseline and weekly during the training. All participants completed pre-and post-training simultaneous exercise and speech tasks at a moderate intensity. The results indicated a significant improvement in MIP across 4 weeks of training. Analysis pre-and post-training indicated no significant changes in dyspnea between the groups. A decrease was, however, observed in recovery time providing potential for functional gains for individuals who must complete exercise and speech simultaneously.
THE EFFECT OF INSPIRATORY MUSCLE STRENGTH TRAINING ON VENTILATION AND DYSPNEA DURING SIMULTANEOUS EXERCISE AND SPEECH

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 Jamie Eileen Luketic
Miami University
Oxford, OH
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Advisor_____________________
Susan Baker, Ph.D.

Reader_____________________
Helaine Alessio, Ph.D.

Reader_____________________
Barbara Weinrich, Ph.D.
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DEDICATION

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CHAPTER 1
Introduction and Review of Literature

Respiration

The fundamental purpose of respiration is to sustain life by providing a means of gas exchange between the environment and the body (Powers & Howley, 2001). This purpose is accomplished through pulmonary respiration, which then allows for cellular respiration or the exchange of oxygen (O₂) and carbon dioxide (CO₂) in the lungs (Powers & Howley, 2001). The efficiency of the system is dependent, in large part, on the function and control of the muscles required for respiration (Seikal, King & Drumright, 2000). During physical exercise more O₂ is needed, which causes a subsequent increase in muscular effort to achieve larger inspirations. The production of speech also requires larger inspirations, but not as large as during exercise. Increased muscular effort and faster muscle contractions are required, since the inspirations must be quick and less frequent in order to preserve phrasing. Some activities require simultaneous exercise and speech, such as talking while walking or leading an exercise class. This combination of exercise and speech places a set of unique demands upon the respiratory system. In order to appreciate the complex competition within the respiratory mechanism during simultaneous exercise and speech, it is necessary to understand the physiology of respiration during each task in isolation beginning with a discussion of basic respiratory function at rest.

Quiet Breathing

The most basic type of respiration, called quiet breathing, is the act of ventilation and gas exchange completed at rest. Quiet breathing is characterized by active inhalation and passive exhalation (Zemlin, 1998). Active inhalation is accomplished by the contraction of the diaphragm and external intercostals, which causes the expansion and elevation of the lung-thorax unit. When the thorax expands, air flows into the lungs until the pressure equals the pressure outside the lungs. Passive exhalation involves the restorative and recoil forces of the ribs and the elasticity of the lungs which displaces air from the lungs (Zemlin). In adult men and women, approximately 500 mL of air is exchanged during 12 to 18 cycles per minute during quiet breathing (Seikal et al., 2000;
Breathing During Exercise

One activity, which places additional metabolic demands on ventilation and pulmonary respiration, is exercise. Exercise increases the demands of gas exchange and therefore increases the muscular effort required by the respiratory mechanism (West, 2000). Sustained muscle contractions, which take place during exercise, create increased demand for energy. Therefore, higher VO₂ (oxygen consumption) levels are required for aerobic energy production in order to fuel the working limb and respiratory skeletal muscles for activities lasting longer than a minute (Powers & Howley, 2001). In order to perform work or exercise successfully, ventilation must increase in order to meet the demands for O₂ and eliminate CO₂. Breathing during exercise is characterized by forced inspiration and expiration with muscular assistance. Forced inspiration requires the contraction of the diaphragm and the external intercostals, with the addition of accessory muscles of the neck, chest, shoulders, and back (e.g., pectoralis minor, scalene muscles, and sternocleidomastoid muscles) to elevate and expand the lung-thorax unit. Expiration during exercise involves the contraction of the internal intercostals and abdominal muscles (e.g., rectus abdominus and internal oblique) to assist the restorative and elastic properties of the lungs and diaphragm to displace the air from the lungs (Powers & Howley).

Due to the need to increase inspired air during exercise, there is a greater active contraction of the inspiratory muscles when compared with quiet breathing or speech. During exercise, an individual inspires 70-85% of his or her vital capacity (amount of air expelled following maximum inspiration; Powers & Howley, 2001). The demands of both the rapid and deep inflation and deflation of the lungs adds to the work of the muscles of inspiration and expiration (Robergs & Keteyain, 2003). This increased work of the muscles of respiration as workload increases ultimately affects cardiac output and contributes to an increase in whole body O₂ consumption.

Breathing During Speech

A second activity, which places unique behavioral demands on ventilation and pulmonary respiration, is the production of speech. The three subsystems of speech are
the pulmonary power supply (respiration), the laryngeal valve (phonation), and the supraglottic vocal tract resonator (resonance; Stemple, Glaze, & Klaben, 2000).

Respiration is the power source for phonation; therefore, vocal fold vibration is dependent upon the lungs as well as the abdominal and thoracic muscles to generate continuous airflow by which sustained phonation can be achieved (Hixon, 1973; Stemple et al., 2000). Hixon (1973) reported that there is an overall range of lung volumes (35-70% of vital capacity) for speech production and that deeper breaths occur during conversational speech compared with quiet breathing.

Respiration requires muscle contractions, but restraining and controlling the airflow and air pressure for speech require additional muscle activity (Seikal et al., 2000). During speech production, respiration is altered to extend expiration and restrict the airflow by the process of inspiratory checking (Seikal et al.). Inspiratory checking is contraction of the inspiratory muscles during exhalation which allows the speaker to accurately control pressure beneath the vocal folds (Seikal et al.). More specifically, after inhalation for speech production, the volume of inspired air in the lungs creates increased relaxation and recoil forces of the diaphragm and lungs secondary to increased expansion (Zemlin, 1998). In order to counteract a high rate of airflow created by a larger inspiration, the inspiratory muscles, primarily the diaphragm and the external intercostals, continue to contract as long as the relaxation force is higher than that required for speech (Zemlin). Then, as the exhalation for speech production continues, the volume of air in the lungs decreases. With lower relaxation forces, the need for inspiratory checking decreases (Zemlin). At this time, the expiratory muscles begin to contract to further restrict the airflow and maintain air pressure in order to elongate the speech utterance (Zemlin).

Breathing during speech represents the competition between the behavioral restrictions posed by both linguistic and ventilatory demands of speech production and the metabolic need for gas exchange. Two factors emerge from the examination of breathing during speech production. The first is that breathing during speech is primarily driven by linguistic factors (Grosjean & Collins, 1979; Winkworth, Davis, Ellis & Adams, 1994). The second is that breathing during speech is characterized by increased voluntary control of the ventilatory response to the metabolic demands for gas exchange.
One important factor associated with behavioral control of breathing during speech is the specific influence of the linguistic structure of the utterance. Grosjean & Collins (1979) found that during reading, inspirations occurred at grammatically appropriate boundaries and that individuals sacrificed metabolic efficiency in order to coordinate these inspirations with grammatically appropriate boundaries. This sacrifice is supported by the continuation of speech on exhalation to O₂ levels that are below typical quiet breathing levels. Furthermore, Winkworth and colleagues (1994) reported that in contrast to the regularity of increased lung volumes during quiet breathing, larger lung volumes during speech were characterized by greater variability. However, the timing of the inspiration was determined by grammatical location (placed at grammatical boundaries). Therefore, the individual’s attempts to fulfill metabolic needs were confined by the grammatical construction of the passage.

**Speaking in High Respiratory Drive**

The greater behavioral control of ventilation during speech inhibits the ability of an individual to respond to metabolic demands for gas exchange. Bailey and Hoit (2002) conducted a study of 10 men performing a breathing task and speaking task in the conditions of room air and air with high concentration of CO₂. The results indicated that quiet breathing in the high CO₂ condition was characterized by increased tidal volume and breathing frequency. Breathing during speech under the same conditions was characterized by decreased breath frequency. This occurred while inspiring the same tidal volume. Furthermore, speaking in high respiratory drive (air with high CO₂ concentration) was characterized by decreased ventilation compared with the breathing-only task under the same conditions. This pattern of ventilation maintains the linguistic structure of the speech utterance and does not increase inspiratory checking action, but sacrifices the metabolic efficiency of gas exchange. The behavioral control of ventilation leads to greater metabolic costs for the participants. This was demonstrated by subjective reports of the perception of increased muscle effort and the reported challenge of coordinating speech and breathing during the high CO₂ condition compared with the breathing only task under the same conditions. These results support the earlier studies.
conducted by Bunn and Mead (1971) and Phillipson and colleagues (1978), who also reported decreased ventilation during high respiratory drive.

While a CO₂ concentrated air condition can be created in the laboratory, simultaneous exercise and speaking tasks are another effective and practical method to study breathing and speaking during the conditions of high respiratory drive. Simultaneous exercise and speech creates a direct competition between metabolic demands for normal gas exchange and the behavioral control needed for effective speech production. The increased demand for oxygen during exercise leads to greater inspiratory volumes. However, these larger lung volumes are inefficient for speech production due to the increased work required by the inspiratory muscles when counteracting the relaxation and recoil forces of the lung-thorax unit (inspiratory checking; Seikal et al., 2000). The larger the inspired volume of air, the greater the relaxation pressure and recoil forces are in the lungs and diaphragm. The lung pressure and volume for breathing during speech is restricted, so as not to create excess relaxation and recoil forces (Hixon, 1973); yet, this restricted lung pressure and volume inhibits the normal function of the system to perform gas exchange.

The knowledge of the complex interaction between the metabolic and behavioral control during simultaneous exercise and speech is the result of a small number of studies dedicated to this topic. Only, three studies have been conducted which demonstrate the balance between the demands of exercise and speech. The first two studies indicate the specific physiological responses to simultaneous exercise and speech. The third study indicates the specific changes of speech parameters.

Decreased ventilation, in the presence of increased metabolic demands during simultaneous exercise and speech was first reported by Doust and Patrick (1981). These researchers conducted a study of 6 healthy participants during treadmill exercise with five grades of intensity. The participants exercised for a total of 7 minutes and began a reading passage at the 5th minute. Analysis of the data indicated a 55% decrease in ventilation during speech segments compared with exercise–only segments. Furthermore, the reduced ventilation values were due to the decreased breathing frequency during the speaking segments as tidal volume remained constant across both segments. Immediately following completion of the speaking task, ventilation increased
by 14% and then returned to baseline measurement within 30 seconds. This study demonstrated how the constraints of airflow necessary for effective speech production interfere with metabolic needs for gas exchange during treadmill exercise.

In another study of simultaneous exercise and speech conducted by Meckel, Rotstein, and Inbar (2002) similar results were found, but these researchers expanded upon other physiologic changes. The study included 14 healthy participants who completed treadmill exercise at VO2 max levels representing moderate to high intensity exercise (65, 75 and 85% of VO2 max). The participants completed 6 minutes of exercise and 6 minutes of simultaneous exercise and speech for each exercise intensity on separate testing days. The results of this study indicated a similarly decreased minute ventilation which was due to decreased breathing frequency, as tidal volume remained constant. Additionally, with the inefficient O2 uptake, the results indicated the high cost of maintaining speech production by increased anerobic energy production (higher blood lactate levels) during simultaneous exercise and speaking tasks compared with the levels found during the exercise-only tasks. This study demonstrated the high physiologic cost of sacrificing normal gas exchange and energy production as a result of the behavioral control of ventilation during simultaneous exercise and speech.

While physiologic changes during simultaneous exercise and speech are important to recognize, they are not the only factors indicative of the competition between the metabolic and behavioral demands of this task. Therefore, Baker, Hipp, Alessio (under review) examined temporal speech measurements (i.e., syllables-per-phrase and inappropriate pause placement) during simultaneous exercise and speech. In this study 12 healthy individuals participated in moderate and moderate-high intensity exercise (50 and 75% of VO2 max) on a bicycle ergometer. The participants successfully completed 18 minutes of exercise-only at both intensities, as well as 18 minutes of simultaneous exercise and speech (with 15 second breaks every 3 minutes) at 50% of VO2 max and 9 minutes of simultaneous exercise and speech at 75% of VO2 max on separate testing days.

The results of the study conducted by Baker, Hipp, & Alessio (under review) indicated changes in both the physiologic and temporal speech measures studied. The physiologic measure of fractional expired O2 (FEO2) was recorded as an indirect measure...
of ventilation. Fractional expired O₂ was significantly decreased during the simultaneous exercise and speaking tasks compared with the exercise-only tasks; therefore, it is presumed that ventilation was decreased during the speaking tasks. However, the analysis also focused on the temporal speech measures of syllables-per-phrase and inappropriate pause placement (pauses at non-grammatical locations). These measures are known to be stable due to the behavioral control which occurs during speech (Bailey & Hoit, 2002; Winkworth et al., 1994). Therefore, any change in these measurements during simultaneous exercise and speech would suggest the influence of increased metabolic needs and a redirection of behavioral control.

The increased demands of the simultaneous exercise and speech task caused significant changes to both syllables-per-phrase and inappropriate pauses. Due to increased breathing frequency during the simultaneous exercise and speech task, the participants had a deceased number of syllables-per-phrase compared with the baseline reading and the number of syllables-per-phrase continued to decrease over the course of the task. In addition, due to the increased demand for O₂ during the simultaneous exercise and speech task, the instances of inappropriate pauses were significantly greater during both exercise intensities and continued to increase as the task progressed. Furthermore, the intensity of the task influenced the degree of change for both syllables-per-phrase and inappropriate pauses. The participants had fewer syllables-per-phrase and greater instances of inappropriate pauses when simultaneously exercising and speaking at 75% of VO₂ max as compared with 50% of VO₂ max.

The decreased syllables-per-phrase and increased number of inappropriate pauses demonstrated during simultaneous speech and exercise indicates the greater metabolic demand of this task. Based on the FEO₂ values during the two tasks, ventilation is lower during speech. Therefore, it is necessary to inspire more often when performing a simultaneous exercise and speech task, which impacts the linguistic components of the speech utterance; specifically, decreased syllables-per-phrase and the inability to place inspirations at grammatical locations. The effect of simultaneous exercise and speech on these two stable variables provides indirect evidence of the increased muscular effort needed to complete the task, especially the muscles of inspiration due to more frequent
inspirations and the greater need to control the larger inspiratory volumes (inspiratory checking).

_Dyspnea_

Simultaneous exercise and speech is characterized by increased muscular contractions, due to more frequent and deeper inspirations to meet the increased demands for O₂ to complete the task. As a result of the attempt to use typical speech breathing patterns during this task, restrictions are placed on the respiratory mechanism, such as decreased inspiratory volume and the placement of grammatical markers in the passage, which inhibit the primary function of respiration for normal gas exchange. This creates a situation of increased muscular effort in the presence of a lack of O₂. Therefore, simultaneous exercise and speech has the potential to create the sensation of breathlessness called dyspnea.

Dyspnea is a subjective measurement defined as an uncomfortable sensation of struggling to breathe (De Peuter et al., 2004; Manning & Schwartzstein, 1995; Salzman, 1997) and is one of the most common medical symptoms reported by patients (Salzman). The sensation of dyspnea is associated with situations in which the respiratory mechanism is working at a high respiratory drive or exposed to a large mechanical load (Manning & Schwartzstein). In these conditions the individual reports the sensation of air hunger and/or an increased effort of breathing (Elliot et al., 1991; Simon et al., 1990). The specific intensity of the sensation of effort is subject to individual variability. Some individuals are able to tolerate an increase or decrease in ventilation without the sensation of dyspnea, while others may report dyspnea without a change in ventilation (Salzman).

The activation and control of the respiratory mechanism is dependent upon the proper functioning of two types of receptors located in the neurologic system and the respiratory apparatus. Chemoreceptors are located in the medulla and carotid bodies and mechanoreceptors are located in the airways, chest and abdomen (Salzman, 1997). Disease processes or activities that disrupt the receptors have the potential to create or intensify the sensation of dyspnea (Salzman). Several conditions may increase the likelihood for dyspnea to occur, including pulmonary, cardiovascular or neuromuscular disorders. Additionally, healthy individuals experiencing intense emotions or completing heavy exercise may also experience dyspnea (De Peuter et al., 2004; Salzman). Any task
which creates increased muscular effort with a lack of O\textsubscript{2} or a condition which impairs the function of the respiratory mechanism to complete gas exchange at rest has the potential to cause dyspnea.

The actual intensity of dyspnea is dependent upon both mechanical and chemical levels of respiratory function. Essentially, the mechanoreceptors are responsible for activating the muscles of respiration within the lung volume parameters necessary for ventilation, while the chemoreceptors are responsible for sensing the appropriate levels of oxygenation. When the demand for ventilation exceeds the activation of the muscles necessary for the increased respiratory effort, abnormal blood gas levels are present which causes the sensation of air hunger (Lansing, Im, Thwing, Legedza, & Banzett, 2000).

The first level of functioning with respect to the sensation of dyspnea is the afferent feedback originating from the muscles of the respiratory system (De Peuter et al., 2004; Manning & Schwartzstein 1995). Ventilation requires the mechanoreceptors, which are ultimately controlled by the brainstem, to appropriately sense the amount respiratory muscle activity (primarily within the diaphragm and the intercostals muscles) necessary for effective ventilation (Manning & Schwartzstein). The sensation of dyspnea is created by the difference between the effort of the respiratory muscles to perform the act of ventilation and the actual amount of air inhaled (De Peuter et al., 2004). The central motor command to the respiratory muscles may be increased as the result of load increases to efficiently operating muscles, or the result of muscles weakened by fatigue, paralysis or an increase in lung volume. For instance, breathing during speech is characterized by the need for higher lung volumes in the presence of decreased breathing frequency, which results in the muscles of respiration contracting more often and with more velocity (Bailey & Hoit, 2002). Greater respiratory effort due to increased motor command positively correlates to increased dyspnea for individuals who are both healthy or disordered (Manning & Swartzstein).

The second level of function is the respiratory motor command or the signal originating from the central nervous system with information regarding blood gas levels (De Peuter et al., 2004; Manning & Schwartzstein 1995). The specific state of the blood gas levels may be related to hypercapnia (high levels of CO\textsubscript{2}) or hypoxia (low levels of
Dyspnea is the result of reduced ventilation due to a decreased capability of muscles to respond to the demands of respiration and increased levels of CO$_2$ in the blood (Schwartzstein, Simon, Weiss, Fencl, & Weinberger, 1989).

The previously discussed study conducted by Baker, Hipp, Alessio (under review) examined the effect of simultaneous exercise and speech on temporal speech parameters and results indicated that dyspnea ratings (on a scale from 0-10, with 0 being no breathlessness and 10 being maximum breathlessness) were higher for participants during the simultaneous exercise and speech task compared with the exercise-only task during both the intensities (moderate and high). Interestingly, even though FEO$_2$ was lower during the simultaneous exercise and speech task, it remained constant throughout the task. Yet, the sensation of dyspnea for the participants continued to increase over the same time period. These results suggested that speech imposes additional demands on the respiratory system, specifically the muscles involved in ventilation, which ultimately impacts the effort associated with the task and increases the sensation of dyspnea. Additional muscular effort is required during simultaneous exercise and speech for more frequent and deeper inspirations, which are in addition to the inspiratory checking needed to control the airflow. It was hypothesized that the two underlying functions of dyspnea, motor command and afferent feedback, interacted during the simultaneous exercise and speech tasks to cause increased dyspnea.

**Dyspnea During Exercise and Speech**

The competition between metabolic demands and behavioral control during speech creates greater inspiratory muscle effort in conjunction with a lack of O$_2$. This scenario causes the potential for dyspnea to occur. Healthy individuals can effectively adjust respiration to balance these demands. However, disease processes which affect the respiratory mechanism, such as asthma, inherently influence the individual’s ability to respond to the increased demand for inspiratory muscle contractions, thereby increasing the intensity and impact of dyspnea for these individuals. This influence and impact is clearly demonstrated in previous studies which examined breathing during speech in individuals with respiratory disease (Lee, Chamberlain, Loudon, & Stemple, 1988; Loudon, Lee, & Holcomb, 1988; Lee et al., 1993). Since some underlying disease processes inhibit normal gas exchange, breathing during speech for an individual with a
disorder affecting the respiratory mechanism is characterized by the metabolic needs of respiration overriding the behavioral demands of speech production resulting in compromised speech.

Loudon, Lee, and Holcomb (1988) conducted a study to determine the specific effects of respiratory disease on the respiratory volume and flow during speech by comparing participants with asthma and healthy participants. The results indicated that individuals with asthma inspire to a higher percentage of vital capacity compared with healthy participants completing the same task, and during speech the volume of air expired is reduced compared with volumes of healthy participants. With regard to overall airflow during speech, individuals with asthma presented with slow inspirations and fast expirations. With more specific analysis of the speaking tasks, this study found that during conversation tasks, speech segments were shorter than those produced by healthy participants. Additionally, decreased respiratory cycle time was noted with increased respiratory rate and a greater proportion of the cycle dedicated to inspiration. These results are similar to the findings of the research conducted by Lee and colleagues (1993), and support that lung disease processes affect ventilation during speaking tasks, which would further influence the individual’s ability to maintain the behavioral control of ventilation during speech.

Lee, Chamberlain, Loudon, & Stemple (1988) extended this research and found increased pause time between segments, fewer syllables per breath, and a larger percentage of time in non-speech ventilatory activity in the participants with asthma when compared with healthy participants. The counting tasks performed in the Loudon and colleagues (1988) study provided crucial insights into the extent of behavioral control of the respiratory system. During the task, the expired volume of air for the participants with lung disease was similar to the value of the healthy participants possibly due to the environmental temporal control through the use of a metronome. However, the reported physiologic and perceptual measurements after the task indicated the respiratory consequences of this similarity. The participants with respiratory disease terminated the task earlier and reported increased dyspnea following the completion of the task.

The competition between metabolic demands and behavioral control is even greater during a simultaneous exercise and speech task compared with speaking at rest.
Due to the nature of the task, there are increased inspiratory muscle contractions, which must be balanced with the ventilatory and linguistic restrictions posed by speech. This decreases the efficiency of gas exchange and causes increased muscular effort, which creates the potential for dyspnea for both individuals with a compromised respiratory system and healthy individuals.

Individuals with upper respiratory disorders, such as exercise-induced vocal fold dysfunction or laryngeal and lower respiratory disorders, such as asthma or chronic obstructive pulmonary disease (COPD), have a decreased capability for O₂ delivery. These individuals have a compromised ability to successfully complete respiration for life support. Therefore, speaking during even light physical activity causes increased muscle fatigue, which results in increased breathlessness. This breathlessness has the potential to impact the individual’s ability to complete daily activities, possibly resulting in the need to frequently choose between speaking and completing the activity. This situation can negatively impact the individual’s quality of life (Lee, Frisen, Lambert & Loudon, 1998).

Healthy individuals, whose professions require the production of speech while exercising, may also be negatively affected by dyspnea. These individuals include vocalists performing simultaneous choreography, fitness specialists (i.e. dance instructors or aerobic instructors), physical education teachers, military drill instructors or army commanders, and emergency personnel. These individuals must efficiently complete physical work, while effectively communicating their message. The increased metabolic and behavioral demands of this task lead to the increased sensation of breathlessness, which can impact the intelligibility of speech or, in extreme situations, cause the individuals to choose between completing the task and speaking. Consequently, the individuals are forced to compromise the efficiency and effectiveness of performing the responsibilities of the job.

_Recovery_

The previous discussion focused on the behavioral and metabolic demands of simultaneous exercise and speech during task completion. Yet, the physiologic effects following the simultaneous exercise and speech task provide a more complete understanding of the exact demands and consequences of such a task. Therefore, another
possible functionally-limiting factor for both healthy and disordered individuals is the recovery time associated with the completion of a simultaneous exercise and speech task. For the healthy individual, a longer recovery period could negatively impact job performance or productivity. The quality of life for an individual with a respiratory disease may be negatively impacted at times when longer recovery is needed. The individual would constantly need to balance the cost of speaking while completing even light physical exercise or work, and the consequent recovery time associated with that task.

A period of recovery is associated with all work or exercise tasks; however, the demands of a simultaneous exercise and speech task have the potential to influence the length of this recovery time. Respiration is possible due to muscular contractions (inspiratory and expiratory muscles) and any additional demands, such as exercise or speech, on the system require greater muscular activity. Respiration during exercise and speech, therefore, is characterized by greater muscular contractions, specifically the inspiratory muscles. The increased muscle contractions are the result of greater metabolic demands for larger lung volumes and the increased restrictions of behavioral demands, particularly increased demand on inspiratory checking. This greater muscle activity results in the potential for increased muscle fatigue and the need to use stored energy to complete the task (Roberg & Keteyain, 2003), which impacts the recovery time.

The recovery time following exercise serves two main metabolic purposes. The first is to continue to remove waste or by-products from the system, such as lactic acid, and to restore the energy stores used during exercise (Roberg & Keteyain, 2003). This recovery can be accomplished by either passive recovery or active recovery. Passive recovery occurs once exercise has been terminated and recovery is promoted by replenishing the used energy sources (Roberg & Keteyian). Active recovery occurs during continued exercise at lower intensity. Recovery is inhibited by the continued depletion of energy sources; however a limited amount of energy can be restored during this time (Roberg & Keteyian).

During the recovery period, metabolism is greater immediately following exercise, characterized by increased oxygen uptake, and is called excess post-exercise
oxygen consumption (EPOC; Powers & Howley, 2001). The magnitude and duration of the increased oxygen uptake during recovery is related to the intensity of the exercise. There is a greater oxygen uptake for a greater amount of time following high intensity exercise (Powers & Howley).

In addition, the recovery period following exercise can be divided into two segments called the fast and slow phases. Early work by Margaria, Edwards, and Dill (1933), which was based on the work of Hill and Lupton in 1923, defined the phases of recovery. This research defined the fast phase of exercise recovery as the 2 to 3 minutes following exercise, which are characterized by a rapid decline in oxygen uptake. The slow phase of exercise recovery is defined as recovery time greater than 30 minutes following exercise characterized by a gradual decline in oxygen uptake.

Williams and Horvath (1995) discussed the fast and slow phases of recovery following exercise in greater detail. These researchers considered the fast phase of recovery to be minutes 1 to 7 of recovery, while the slow phase consisted of minutes 10 to 60. The phases of recovery were analyzed in terms of both cardiovascular parameters (e.g. HR) and metabolic parameters (e.g., minute ventilation, O₂ uptake, and CO₂ uptake). The results of this study indicated that in terms of phases of recovery the cardiovascular and metabolic variables were unaffected by changes in exercise duration and intensity during the slow phase of recovery. However, during the fast phase of recovery the cardiovascular variables remained unchanged, while the metabolic variables were affected. This was demonstrated by elevated minute Ve for a longer period of time, immediate decrease then increase in O₂ uptake, and a drop in CO₂ uptake during the recovery period following exercise for 30 or 45 minutes compared with 60 minutes of rest. Therefore, the fast phase of recovery demonstrates changes for recovery parameters, specifically the metabolic measurements.

Speech tasks alone, as well as simultaneous exercise and speech tasks, place additional demands on the respiratory mechanism, and therefore impact the recovery period following these activities. One major factor is that due to decreased ventilation during tasks, such as prolonged speaking (Hoit & Lohmeir, 2000) and simultaneous exercise and speech (Doust & Patrick, 1981), ventilation is elevated immediately following the completion of both these tasks. Hoit and Lohmeir conducted a study of two
breathing situations: quiet breathing and breathing following prolonged speaking tasks. The results indicated increased variability of breath-by-breath measures of minute volume, tidal volume, and breathing frequency both during and after prolonged speaking compared with quiet breathing. The recovery period was characterized by larger minute volumes that were the result of either increased tidal volume or breathing frequency following quiet breathing, and the result of both increased tidal volume and breathing frequency following prolonged speaking (Hoit & Lohmeir). In addition, this variability was the greatest for the initial 5 to 10 breaths following speaking (Hoit & Lohmeir). Similar changes in ventilation occur during the fast phase of recovery following simultaneous exercise and speech. Doust and Patrick (1981) reported that ventilation during the recovery period from treadmill exercise while speaking was immediately increased by 114% in the first 15 seconds of the recovery period, then declined to baseline value within 30 seconds. These findings indicate that speech production, alone and during exercise, not only influences ventilation during the task, but also creates changes in ventilation during the recovery period.

The study of recovery in terms of the fast phase and slow phase is just one method to study the recovery period. Another method to analyze the changes that occur during recovery is to classify the changes by either subjective recovery or physiological recovery. Wu, Hsu and Chen (2005) reported the difficulty of determining complete recovery time based on a discrepancy between subjective and physiologic recovery. Subjective recovery was determined based on individual report of the perception of fatigue. No formal scale was used to quantify this perception. Physiologic recovery was determined using cardiovascular and respiratory measurements. They found the subjective recovery time to average 7 minutes and the physiological recovery time to average 11 minutes. Furthermore, analysis of the results indicated additional differences in physiological variables. Cardiovascular recovery measured in terms of heart rate was slower than respiratory recovery measured in terms of VO₂. During the phases of recovery, it is important to consider the discrepancy between subjective and physiological measures, as well as the specific physiological measurement parameters, in order to achieve the most accurate analysis.
Inspiratory Muscle Strength Training

Baker, Hipp, and Alessio (under review) provided data which suggested that the inspiratory muscles are specifically fatigued during simultaneous exercise and speech. During this task, FEO$_2$ values were lowered compared with exercise-only tasks. The lowered FEO$_2$ remained consistent for the duration of the task, while dyspnea continued to increase over the same time period. The increase in dyspnea is likely due to the increased inspiratory muscle effort (inspirations of larger volumes and inspiratory checking) during the task. Therefore, a training method that specifically targets the inspiratory muscles may be beneficial to the individuals who are required to complete simultaneous exercise and speech. Inspiratory muscle strength training (IMST) is one method that specifically targets these muscles.

Principles of Muscle Training

The muscles of respiration are skeletal muscles and it is known that these muscle fibers can be altered by an increase in physical activity (Powers & Howley, 2001). Therefore, specific muscle training programs, namely inspiratory muscle strength training, have been developed based on the same principles that govern the training of other skeletal muscles (i.e., limb muscles). Training programs that successfully combine the three principles of specificity, overload, and progressive resistance exercise are known to increase muscle strength and endurance. These gains occur when the training program targets the isolated muscle groups and the specific movement patterns associated with the performance of a certain skill (Robergs & Keteyain, 2003).

The first principle of training is specificity. This principle suggests that quantifiable effects of training are specific to the muscles involved in the activity and to the types of muscle adaptations that occur as a result of the training (Powers & Howley, 2001). The methodology used to achieve the training specificity must take into consideration the contraction pattern of the specific muscles used to overcome the training load and the potential of those muscles for either strength training or endurance training (Lisboa & Borzone, 2005). The training program then must be relevant to the demands of the activity the individual is performing and the movement patterns of the specific muscles involved in the activity (Robergs & Keteyain, 2003). Muscles have a specific response to the type of training implemented. For example, strength or
resistance training has the potential to increase muscle size and increase force production (Powers & Howley, 2001).

The second principle is overload. This principle states that the muscle must be trained with a load that requires effort higher than normal in order to promote muscle adaptation (Powers & Howley, 2001). The specific variables associated with overload are the intensity of the load, the duration of training at the load, and the frequency with which the training occurs (Powers & Howley).

The third principle is progressive increase of load, called progressive resistance exercise (PRE; Powers & Howley, 2001) and is closely related to the second principle of overload. The principle of progressive resistance exercise states that in order to improve the overall strength of the specific muscle, effective training must combine the principle of overload with the periodic increase of the resistance used to complete the exercise. In other words, as the muscle gains in strength and endurance the resistance against which the muscle works is increased. The use of PRE in training has become the basis for most weight training programs (Powers & Howley).

**Training Modalities**

Effective inspiratory muscle strength training programs incorporate the known principles of training. There are several modalities which provide training to the inspiratory muscles. Each method recruits muscles, relies on specific contraction patterns, and provides strength or endurance training specific to that modality of training. There are three methods for IMST: (a) normocapnic hypernea, (b) inspiratory resistive breathing, and (c) inspiratory pressure threshold training.

Normocapnic hypernea is described by Lisboa and Borzone (2005) as a method of training both the inspiratory and expiratory muscles in the laboratory setting. The individual produces the highest minute ventilation possible for 10-15 minutes, while ventilation is monitored via a rebreathing circuit. Therefore, this method of training is not effective for home training due to the equipment required to create a controlled environment.

The second method is called inspiratory resistive breathing. During resistive load training an individual inspires through a hand-held device which contains holes that can be decreased in diameter in order to change the inspiratory resistance. Resistive load
training may not be as effective as other methods of training due to the ability of the 
individual to decrease the flow rate of the inspiration during the training. This decrease 
in flow rate reduces the effort needed to complete the training making the training less 
effective overall (Belman, Thomas, & Lewis, 1986). This training method can be made 
more effective by having the individual produce a targeted flow rate. During this training 
the individual must generate the target inspiratory flow rate, and maintain that rate using 
a device set to a specific percentage of their maximum inspiratory flow rate, which 
provides visual feedback concerning the accuracy of the training (Lisboa & Borzone, 
2005). However, this type of training must be completed in a laboratory setting due to 
the specific equipment needed to maintain accurate measurements, and therefore is not 
conducive to training in a home setting.

The third method of IMST is pressure-threshold training. The training device used 
for the method requires an individual to create a specific negative pressure in order to 
open a one-way valve, resulting in the ability to then inspire (Lisboa & Borzone, 2005; 
McConnell & Romer, 2004). This training method can be achieved through the use of 
several device designs; however, the most common is a spring-loaded valve. Many 
devices are commercially available, including POWERbreathe (Leisure Systems 
International, Southam, UK). There are three main advantages to this modality of IMST: 
(a) the pressure load can be changed and quantified, (b) the pressure is not dependent on 
the individual’s inspiratory flow rate, and (c) this modality of training has been 
successfully carried out in the home setting with periodic supervision of training in the 
laboratory setting (Lisboa & Borzone, 2005; McConnell & Romer, 2004). These 
advantages make pressure threshold training the most common modality of training in 
current research studies conducted with participants who are both healthy and disordered.

Inspiratory Muscle Training Considerations

When implementing an IMST program there are several important factors to 
consider. First, the intensity of the training should be considered in the development of a 
program. It is important to consider the highest training load that produces the desired 
changes, as well as the training load at which no measurable change occurs. This range 
varies depending on the status of the population. The measurement used to determine 
inspiratory muscle strength during inspiratory muscle training is maximum inspiratory
pressure (MIP). For healthy participants training at loads of 50 to 80% of MIP, positive adaptive responses have been reported, demonstrated by an increase in MIP (Caine & McConnell, 1998a; Gething, Passfield, & Davies, 2004). On the other hand, training loads of 15% MIP and 25% MIP produce insignificant changes in inspiratory pressure and performance (Caine & McConnell, 1998b; Volantis et al., 2001). For participants with respiratory diseases, such as COPD, training loads are reportedly lower. The majority of training occurs at 30% MIP and this effectively achieves measurable changes in inspiratory muscle strength (Larson et al., 1988; Lisboa et al., 1997; Lisboa, Munoz, Beroiza, Levia, & Cruz, 1994). In contrast, insignificant training effects for this population occur at training loads between 10% to 15% MIP (Larson, Kim, Sharp & Larson, 1988; Lisboa, Munoz et al.; Lisboa, Villafranca et al.). The negligible changes occurred since the principle of overload was not applied to the training program.

The second factor to consider when developing an IMST program is to determine the length of the training program. From the current IMST research there is not yet a recommended duration of the IMST program that has emerged, as the training frequency and days vary so greatly between studies (Lisboa & Borzone, 2005). However, the majority of current examinations of IMST use a training program consisting of one to two 15-minute sessions per day for 5 to 6 days per week. In order to maximize the training benefit, the program should last no less than 4 weeks. Studies implementing IMST programs report that MIP continues to increase during the first 4 to 6 weeks of the program, at which time there is a noted plateau in MIP, which indicates a leveling of inspiratory muscle strength gains (Larson, Kim, Sharp, & Larson, 1988; Lisboa et al., 1997). Additionally, studies concerning the changes of muscular strength following generalized muscle training indicate that within the first 4 weeks of training increased muscular strength may be contributed to neural adaptations which increase the ability of the nervous system to activate the muscle (Sale, 1988).

Outcomes of IMST Programs

A variety of outcomes have been measured following IMST programs with healthy individuals, as well as with individuals with respiratory disorders. Many of the studies have focused on the outcomes of increased respiratory muscle strength and increased endurance (Lisboa & Borzone, 2005). Yet, clinically relevant outcomes, such
as the effects of IMST training on dyspnea, exercise tolerance, and quality of life have been limited.

The application of the principles of strength and endurance training to respiratory muscles in healthy participants was first reported by Leith & Bradley (1976). These authors found increased strength of inspiratory muscles and improved respiratory endurance in participants following 5 weeks of specific training. These results were supported by increased MIP and greater maximum voluntary ventilation and were independent of significant changes in total lung capacity or vital capacity.

Recent research concerning the use of IMST programs with healthy participants have examined the effect of training on variables, such as lung volume, exercise capacity, resistive load detection (the intensity of work performed), and magnitude estimation (the effort associated with performed work) of a specific load. A study of a 4-week IMST program conducted by Kellerman, Martin, & Davenport (2000) found that while MIP was increased post-training, magnitude estimation (the effort associated with the work) was decreased for all participants, except during the highest load tested. In other words, participants detected the same intensity of work, while sensing a decreased effort associated with the work after completion of an IMST program. More specifically, Enright and colleagues (2006) reported that following an intense 8-week IMST program in which participants trained at 80% of MIP, participants demonstrated a significant increase in sustained maximal inspiratory pressure (SMIP). Sustained maximal inspiratory pressure is a measure of the ability to maintain maximal inspiratory pressure over time. This change indicates increased strength and endurance of the inspiratory muscles. In addition, participants had increased exercise capacity, as evidenced by greater exercise duration and greater power output during exercise. IMST had no effect on lung function and caused minimal increase in vital capacity and total lung capacity, at rest. The results of these two studies support the positive impact of IMST on the sensation of effort, inspiratory muscle strength, and exercise capacity and provide a foundation to extend the implications of these findings to other, more specific populations.

One such extension has been research involving the implementation of IMST programs with athletes. Inbar and colleagues (2000) found that following a 10-week
IMST program, 10 endurance athletes improved inspiratory muscle strength by 25% and inspiratory muscle endurance by 10%. These improvements were not associated with changes in VO₂ max or arterial O₂ desaturation during the exercise task. Several studies have demonstrated the effects of IMST programs for specific athletic tasks, such as rowing and cycling. Volantis and colleagues (2001) studied the effect of an 11-week IMST program with 16 competitive rowers. The research indicated an increase in MIP measurements and improved rowing performance evidenced by greater distance covered and faster time-trials at the conclusion of the IMST program. Lower levels of fatigue and decreased deficits in maximum inspiratory pressure were noted following the rowing tasks after the IMST program as well. A second study conducted by Romer, McConnell and Jones (2001) analyzed the effect of a 6-week IMST program with 16 cyclists on time-trial performance for 20 and 40 kilometers. The results indicated a decrease in perceived dyspnea ratings following the IMST program. In other words, the specific training diminished the perceptual response to breathing during the cycling task. Furthermore, the results indicated a 28% increase in MIP measures and faster time trials by 3.8 seconds (20 km) and 4.6 seconds (40 km) after the IMST program. The result of these two studies supports the ability of specific inspiratory muscle training to improve muscle strength and endurance, thus improving athletic performance.

While these studies report greater muscle strength, improved athletic performance, and decreased perception of dyspnea, a study conducted by Romer, McConnell and Jones (2002) extending the examination of athletic performance to measurement of the effects of IMST on recovery time. These researchers reported the effect of a 6-week IMST program on the ability of 24 sprint athletes to recover from a repetitive sprint task. The repetitive sprint task consisted of fifteen 20-meter sprints performed in groups of 5 with 30 seconds of recovery in between each sprint. The recovery time was to be no more than 30 seconds and participants were told to maintain maximal sprint performance while taking as little rest as possible. The results indicated a significant increase in MIP, but no significant change in VO₂, heart rate, or the perception of effort during the sprint task. However, the main finding of the study was the reported decrease in total recovery time of 6.9% for participants following the IMST program. The participants had decreased dyspnea after the sprint tasks following the
IMST program and this may have contributed to the overall decrease in the sensation of effort. Therefore, not only does an IMST program have the potential to increase inspiratory muscle strength and decrease dyspnea, but it can improve recovery time as well.

These positive results reported with healthy individuals and athletes have been extended to the study of IMST programs implemented in participants with respiratory disorders. These studies are categorized by disease processes affecting the lower airway, disorders affecting the upper airway, as well as specific conditions affecting muscular control or lung function. A majority of the research has been devoted to the implementation of IMST programs for individuals with lower respiratory disorders, such as chronic obstructive pulmonary disease (COPD). For example, following a 6-week IMST program with training loads greater than 30% of the maximum inspiratory pressure, Nield (1999) found individuals with COPD had increased inspiratory muscle strength and decreased dyspnea. These results support an earlier study by Lisboa and colleagues (1997). These researchers studied the effect of a 10-week IMST program with the experimental group training at 30% of maximum inspiratory pressure. The results indicated improved exercise performance and decreased sensations of dyspnea following training. More specifically, the results indicated an increase in inspiratory muscle strength (increased MIP) for both training loads, but a decrease in dyspnea and greater distance covered in the 6-minute walking task for the participants training at 30% of maximum inspiratory pressure only. When participants with COPD perform inspiratory training at a training load of 30% of maximum inspiratory pressure, improvements in inspiratory muscle strength positively impact both exercise performance and the sensation of dyspnea.

Inspiratory muscle strength training programs have been found to be effective in increasing inspiratory muscle strength in a variety of other respiratory diseases, such as cystic fibrosis (e.g., Asher, Pardy, Coates, Thomas & Macklem, 1982; Enright, Chatham, Ionescu, Unnithan & Shale, 2004), asthma (e.g., Weiner, Magadle, Massarwa, Beckerman, & Berar-Yanay, 2002), upper airway obstruction (e.g., Baker et al., 2003; Ruddy et al., 2004; Sapienza, Brown, Martin, & Davenport, 1999) and neuromuscular
disorders, such as muscular dystrophy (e.g., Topin et al., 2002; Wanke et al., 1994) and myasthenia gravis (e.g., Fregonezi et al., 2005).

Mechanisms by Which IMST Programs Affect Change

The specific mechanisms by which IMST programs affect positive changes remain unknown, yet important speculations can be made based on research involving healthy participants. It has been shown, through controlled studies, that the positive change are independent of central cardiovascular training effect of variables, such as cardiac stroke volume, VO$_2$ or energy production (Markov, Spengler, Knopfli-Lenzin, Stuessi, & Boutellier, 2001) or a change in the capacity of oxygen transport throughout the system (McConnell & Romer, 2004).

Therefore, the avoidance of respiratory muscle fatigue accompanied by a decrease in the perception of dyspnea is related to other means. One possible factor is changes related to muscular contraction. Three main changes may contribute to a decrease in fatigue by increasing muscular resistance through specific muscle changes, such as: (a) neural adaptations which increase the ability of the central nervous system to activate the muscle (Sale, 1988); (b) functional changes to specific respiratory muscles, such as the diaphragm (Johnson, Babcock, Suman, & Dempsey, 1993); and, (c) specific structural changes to the inspiratory muscles, including increased proportion and size of muscle fibers (Ramirez-Sarmiento et al., 2002). Romer and Dempsey (2002) reported that the fatigue of the respiratory muscles influences the muscular activity of limb locomotor muscles, since blood flow may be reduced to the limb muscles (due to the needs of the respiratory muscles), thus contributing to the fatigue of these muscles. Inspiratory muscle training may diminish fatigue by increasing the blood flow distribution to the limb locomotor muscles during heavy exercise (Romer & Dempsey, 2002). Therefore, the second possible factor is that the improved efficiency of the respiratory muscles, particularly the muscles of inspiration, would allow for the redirection of the blood flow to the limb muscles decreasing the fatigue, thus lessening the perception of dyspnea.

The final possible factor related to a lower perception of dyspnea is the decrease in the perception of effort, which is controlled by the sensory input to the central nervous system. The intensity of breathlessness is greater due to added resistance related to the
completion of the task, as well as decreased muscular function as the muscles become fatigued over the course of the task (El-Manshawi, Killian, Summers, & Jones, 1986). As muscular fatigue develops, individuals begin to overestimate the effort in the presence of the same pressure load (Gandevia, Killian, & Campbell, 1981). Inspiratory muscle training may contribute to a decrease in the sensory input acting through any of these processes to decrease the perception of dyspnea. Specifically, with increased muscular strength, the specific motor command at a certain muscular tension decreases at the same resistance, thus decreasing the potential for the sensation of dyspnea (Redline, Gottfried, & Altose, 1991).

Statement of Problem

The fundamental purpose of the respiratory mechanism is to function as the means of gas exchange for life support. This purpose is adapted based on the demands placed on the system, such as exercise or speaking. However, breathing during simultaneous exercise and speech becomes a complex interaction and balance between the increased demand for oxygen and the additional demands placed on the respiratory mechanism for effective speech production. Increased muscular activity is required by the respiratory muscles, specifically the muscles of inspiration, to control increased volume of air and restrict the airflow through inspiratory checking for effective speech production during exercise. The greater demand for normal gas exchange (i.e., increased breathing frequency) is driven by the metabolic demands of exercise, just as the greater need for effective speech production is driven by the behavioral demands of the linguistic content of the message (i.e., grammatical pauses). The behavioral restrictions created by speech cause adaptations to ventilation which occur at the expense of normal gas exchange. Therefore, the increased demands placed on the respiratory mechanism during simultaneous exercise and speech may create greater muscular fatigue, which produces the potential for two functionally debilitating factors: dyspnea and increased time for recovery. In the case of individuals who are healthy, dyspnea during the task may interfere with job performance and the recovery time may impact their productivity. For individuals who have respiratory disease, the influence of dyspnea and recovery time impact their quality of life due to the high energy cost of completing even light exercise and speaking at the same time.
Statement of Purpose

One potential method to assist these two populations in completing the simultaneous exercise and speech tasks associated with their occupation or daily living is IMST. This non-invasive training program is based on the principles of skeletal muscle training. By specifically targeting the inspiratory muscles, the improved strength may decrease the fatigue associated with the metabolic and behavioral demands of the task. This improvement has the potential to lead to the functional improvement of the previously debilitating symptoms of dyspnea and recovery time.

The purpose of this study was to determine the effect of an inspiratory muscle strength training program on the functionally limiting factors of dyspnea and recovery time in healthy participants during simultaneous sub-maximal, aerobic exercise and speech. The specific aims were to: (a) determine changes in inspiratory muscle strength; (b) determine changes in perceived dyspnea during a simultaneous exercise and speech task; and (c) determine the changes in task recovery time in the study population. In order to perform an unbiased and accurate examination of these specific aims, there was an experimental and sham group completing a 4-week IMST program.

Research Hypotheses

1. Mean maximum inspiratory pressure (MIP) will increase from baseline following a 4-week IMST program at 75% of the participant’s MIP. The change from baseline will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

2. Perceived dyspnea during a 9-minute simultaneous exercise and speech task will decrease following a 4-week IMST program at 75% of the participant’s MIP. The change will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

3. Recovery time (defined by a return of minute ventilation to a level within 15% of baseline) will decrease after a 9-minute simultaneous exercise and speech task following a 4-week IMST program at 75% of the participant’s MIP. The change will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).
Null Hypotheses

1. Mean maximum inspiratory pressure (MIP) will not increase from baseline following a 4-week IMST program at 75% of the participant’s MIP. The change from baseline will not be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

2. Perceived dyspnea during a 9-minute simultaneous exercise and speech task will not decrease following a 4-week IMST program at 75% of the participant’s MIP. The change will not be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

3. Recovery time (defined by a return of minute ventilation to a level within 15% of baseline) will not decrease after a 9-minute simultaneous exercise and speech task following a 4-week IMST program at 75% of the participant’s MIP. The change will not be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).
CHAPTER 2

Methods

Participants

Ten healthy adults (5 males and 5 females) participated in this study (M = 20.7 years; SD = .82). Participants exercised at least 30 minutes at moderate intensity 3 days per week, and had normal pulmonary function (screening procedure described below). The participants’ health history was collected from the completion of a health questionnaire (Appendix A). Participants were excluded from the study if they had a history of heart disease, lung disease, neurological disorders, immune system disease, or voice disorders. Other exclusion criteria were recent illness or a history of smoking within the last 5 years.

Procedure

Pre-Training Measures

*Pulmonary screening.* Baseline pulmonary function test was completed using a spirometer (Spirovision 3+, Future Med) to screen for any abnormal breathing status. Pulmonary function testing required the participants to inhale and exhale forcefully into a mouthpiece to obtain vital capacity. All participants had a forced vital capacity (FVC) and forced expiratory volume (FEV₁) values 80% or above the predicted values for their age, height, and gender (Knudson, Holberg, & Burrows, 1983).

*Maximum oxygen consumption/VO₂ max test.* In order to determine the specific intensity levels at which each participant would work, each participant completed a standard graded exercise test protocol on a stationary bicycle ergometer (Monark, Sweden). The test was used to determine maximal oxygen consumption (VO₂ max) following a progressive workload. Measurement of VO₂ max is a well-established and valid indicator of cardiovascular fitness (American College of Sports Medicine, 2000). For the VO₂ max test, the participants maintain a constant speed as the resistance on the bicycle is gradually increased. The participant’s VO₂ max was determined through a graded exercise test protocol to maximum effort. The participant began pedaling at 50 revolutions per minute against 1 kg resistance. Resistance was increased by 0.5 kg every 3 minutes until the participant declined to continue, or until two of the following criteria were reached: (a) achieved age-predicted maximum heart rate, (b) O₂ consumption
leveled off despite an increase in resistance/workload, (c) O₂ consumption decreased despite an increase in resistance/workload, or (d) respiratory quotient was greater than 1.1. Ventilation, O₂, and CO₂ levels were determined in expired breath measurements and maximum work capacity was measured as maximum oxygen consumption.

Simultaneous exercise and speech task. The participants returned to the lab 1 to 6 days later to complete a Simultaneous Exercise/Speech Task at 65% of their VO₂ max. A timeline of the progression of this task is in Figure 1. During the simultaneous exercise and speech tests, the participants breathed through a facemask (7400 Series Face Mask, Hans Rudolph) that fit over the nose and mouth, versus the more commonly used mouthpiece with nose clips, in order to allow for the production of speech. Heart rate was monitored during this test with the use of a Polar monitor (Polar Electro, Finland). A signal was established between the participant and the investigator prior to the initiation of the exercise test which allowed the participant to inform the investigator that he/she wanted to stop the test immediately.

Figure 1
Simultaneous Exercise and Speech Task Performed at 65% of VO₂ Max

To begin the Simultaneous Exercise/Speech Task, the participants had their baseline Ve recorded at rest for 1 minute wearing the facemask attached to the metabolic cart. Then, the participants switched facemasks in order to perform a baseline recording of speech production. This facemask was attached to a pneumotach which was connected to a multi-channel recording device (Power Lab, Adinstruments). This recording device uses software (Chart 5 for Windows) to capture breath volume and frequency with speech signals simultaneously. This set-up provided breath-by-breath analysis of ventilation, as well as running speech. The participants were asked to read four phonetically balanced passages which are standard in speech science research (Rainbow Passage, California...
Passage, Grandfather Passage, and Zoo Passage; Appendix B). The text for the passages was printed in 20-point font and placed at eye level to allow the participant to read with ease. While speaking, the participants wore a unidirectional condenser headset microphone (AKG C420PP, MicroMic) placed approximately 3 cm from the outside of the facemask and level with each participant’s mouth and attached to an amplifier (Kay Electronics). The microphone is highly sensitive, and noise produced from the bicycle, while in use, did not interfere with the recordings.

Once the baseline recording was taken, the participants switched back to the facemask attached to the metabolic cart to begin the “rest-to-work” transition period. When the participants were stabilized at 65% of VO₂ max, each was asked to begin reading the passages while wearing the facemask attached to the multi-channel recorder. The participants read continuously through the four passages for 3 minutes. During this time, speech was digitally recorded and ventilation measures were collected. Ve during the simultaneous exercise and speech task was averaged for each 15-second segment of the entire 8 minutes and 30 seconds.

The participants were asked to rate their degree of breathlessness during 15 second breaks every 3 minutes (Reading 1, Reading 2, and Reading 3) by pointing to a Borg Scale (Appendix C) held at eye level by the examiner. Once the participants completed 8 minutes and 30 seconds of the task, 30 seconds were taken to switch the facemask while the participant continued to pedal. The participants then wore the facemask attached to the metabolic cart and continued to pedal on the bicycle with the tension for 2 minutes (PR 1 and PR 2) and then without the tension for 2 minutes (PNR 1 and PNR 2). The participants then sat on the bicycle without pedaling (SR) until their Ve returned to a reading within 15% of baseline. Ventilation and VO₂ were recorded each minute of all periods of recovery. Individual participant’s Ve and VO₂ were 30-second increment averages. The total recovery time was determined by the 4 minutes pedaling with resistance and pedaling without resistance combined with the individual participant’s total sitting recovery.

IMST program. The 10 participants were randomly assigned by the primary researcher to either the Experimental Group or the Sham Group. The Experimental Group consisted of 5 participants (3 females and 2 males; mean age = 20.6; SD = .89).
The Sham Group also consisted of 5 participants (2 females and 3 males; mean age = 20.8; SD = .84). The IMST Program and Sham Program were completed over a 4-week period. During the initial meeting for all participants, maximum inspiratory pressure (MIP) was measured with the use of an electronic pressure gauge (350 Smart Manometer, Davis Inotek). Maximum inspiratory pressure is used as an indirect measure of inspiratory muscle strength. The participants stood with nose clips in place. The participants were then asked to blow out the air in his or her lungs to a minimum volume, place his or her lips around a mouthpiece, and inhale as forcefully as possible for approximately 2 seconds. The participants repeated this procedure until they produced 3 MIP measures within 5% of each other (the participants were only allowed to produce 6 of these measures; if 3 measures within 5% of each other were not obtained by the 6th measure, then the greatest 3 measures were used). In order to obtain accurate measures, the participants practiced this procedure two times before the measures were taken.

Each participant was provided with a pressure-threshold trainer (Fitness Model, Powerbreathe). The pressure-threshold trainer consists of a plastic tube with a variable tension spring controlling a “pop-off” valve. Participants in the Sham Group had a pressure-threshold trainer set to a training load that represented 10% of their MIP average. Participants in the Experimental Group had a pressure-threshold trainer set to a training load that represented 75% of their MIP average. When the participants received the pressure threshold trainer, they were given both verbal and written instructions (Appendix D) and a demonstration concerning the proper use of the trainer. The participants then completed the first day of training in the presence of the examiner, so that correct training procedures could be monitored or adjusted. Training consisted of 5 sets of 5 breaths each with no more than a 1 minute break between sets. The participants performed the remaining four training days at home. Compliance was monitored by the participants’ completion of a training log sheet (Appendix E). Participants used the log sheet to record the day, time, and completion of training sets and brought this to the weekly meetings.

Participants met with the investigator after each training week of the 4-week training program (Baseline, Week 1, Week 2, Week 3, and Week 4). The participants’ MIP was measured using the same protocol described previously. The participants in the
Sham Group received a pressure-threshold trainer set to a training load representing 10% of their new MIP average. The participants in the Experimental Group had the trainer set to 75% of their new MIP average. The participants then completed the first of the five training days in the presence of the investigator, so the examiner could adjust the training load and assess the participants’ tolerance of the training load change. In addition, the researcher observed the training techniques, addressed concerns, and maintained participant cooperation and motivation. The remaining four training days were carried out at home with the use of the log sheet as described previously. At the end of the 4-week training program, the training device was collected from the participants.

*Post-Training*

Participants in both the Experimental and Sham Groups completed the VO₂ max testing as described previously. All participants then completed the Simultaneous Exercise and Speech Task at 65% his or her VO₂ max following the same protocol described above.

*Statistical Analysis*

An independent t-test was performed to analyze the difference in percent change in MIP between the two groups (Experimental and Sham). Repeated measure analysis of variances (ANOVA) were performed to analyze the change in mean perceived dyspnea ratings during the task and the total recovery duration pre-and post-4-weeks of IMST. The within-subject factor was weeks and time (pre-training and post-training). The between-subject factor was group (Experimental or Sham). The analyses were completed using the software program SPSS (Version 14.0 for Windows). The alpha level for analysis was set at .05.
CHAPTER IV

Results

The main purpose of this study was to examine the effect of IMST on the variables of interest (MIP, perceived dyspnea and recovery time). The examination of this effect was dependent upon the compliance of the participants during the training (IMST) portion of the study. Several mechanisms to ensure compliance were outlined in the methods section (instructions on use of the trainer, log sheets, and weekly meetings). All 10 participants in the study complied with IMST training procedures by attending the designated weekly training meetings and recording all home training using the training logs. All participants completed the five training days over the 4-week training period, according to the instructions given at the initial meeting. Therefore, the 10 participants exhibited 100% compliance with the training protocol.

Analysis by Research Hypothesis

Research Hypothesis 1

Mean maximum inspiratory pressure (MIP) will increase from baseline following a 4-week IMST program at 75% of the participant’s MIP. The change from baseline will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

The mean MIP values across the 4-week IMST program by group are displayed in Table 1 and Figure 2. Percent change from baseline values were also calculated as baseline MIP varies greatly between individuals, since it is largely determined by gender, age, and height. Formal comparisons were made between groups for this analysis and it was felt that using percent change for these comparisons was more appropriate. The mean percent change from baseline across the 4-weeks of training for groups (Experimental and Sham) is displayed in Table 2. For additional description of the data, due to the variability at baseline, the mean percent change from baseline across the 4-weeks of training for individual participants is displayed in Table 3 and Figure 3.
Table 1

*Mean MIP (cmH₂O) Change for a 4-week Training by Group*

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group (N=5)</th>
<th>Sham Group (N=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Baseline</td>
<td>91.06</td>
<td>26.00</td>
</tr>
<tr>
<td>Week 1</td>
<td>104.68</td>
<td>20.84</td>
</tr>
<tr>
<td>Week 2</td>
<td>108.43</td>
<td>31.84</td>
</tr>
<tr>
<td>Week 3</td>
<td>124.11</td>
<td>31.01</td>
</tr>
<tr>
<td>Week 4</td>
<td>131.04</td>
<td>33.32</td>
</tr>
</tbody>
</table>

Figure 2

*Mean Changes in MIP Measures by Group*
Table 2

*Mean MIP Percent Change from Baseline for a 4-week Training by Group*

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group (N=5)</th>
<th>Sham Group (N=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1 vs baseline</td>
<td>13.94%</td>
<td>-3.34%</td>
</tr>
<tr>
<td>Week 2 vs baseline</td>
<td>15.92%</td>
<td>15.74%</td>
</tr>
<tr>
<td>Week 3 vs baseline</td>
<td>26.70%</td>
<td>18.71%</td>
</tr>
<tr>
<td>Week 4 vs baseline</td>
<td>30.51%</td>
<td>21.54%</td>
</tr>
</tbody>
</table>

Table 3

*Mean MIP Percent Change from Baseline at Each Training Week by Individual*

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experimental Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 1</td>
<td>33.61%</td>
<td>26.67%</td>
<td>26.95%</td>
<td>31.28%</td>
</tr>
<tr>
<td>Participant 2</td>
<td>16.09%</td>
<td>4.60%</td>
<td>15.46%</td>
<td>18.25%</td>
</tr>
<tr>
<td>Participant 3</td>
<td>9.44%</td>
<td>11.67%</td>
<td>40.17%</td>
<td>43.31%</td>
</tr>
<tr>
<td>Participant 4</td>
<td>6.63%</td>
<td>15.37%</td>
<td>27.04%</td>
<td>30.93%</td>
</tr>
<tr>
<td>Participant 5</td>
<td>3.94%</td>
<td>21.30%</td>
<td>23.90%</td>
<td>28.76%</td>
</tr>
</tbody>
</table>

| **Sham Group**         |        |        |        |        |
| Participant 1          | -15.83%| 29.11% | 15.37% | 21.40% |
| Participant 2          | 13.57% | 17.62% | 44.77% | 30.01% |
| Participant 3          | -7.20% | 19.03% | 16.22% | 24.97% |
| Participant 4          | -0.30% | 19.79% | 13.48% | 19.77% |
| Participant 5          | -6.96% | -6.83% | 3.72%  | 11.55% |
An independent t-test was used to analyze the difference in the percent change from baseline after 4 weeks of training between the Experimental and Sham Groups. This analysis revealed that there was no significant difference in percent change between the groups, \( t(8)=1.785, p=.112 \). While there was no significant difference between the groups, it was of interest for future research and development of this project to determine whether there was a significant change in MIP across the 4-weeks of training for the Experimental Group (who had trained at 75% of their maximum MIP). Therefore, a repeated measures ANOVA was completed to analyze MIP across time in only the Experimental Group. The results of this analysis revealed a significant difference in mean MIP measures from baseline over 4 weeks of training, \( F(4)=9.975, p=.0001 \). Furthermore, simple contrasts were used to determine the significance of change from baseline at each training week. The analysis revealed a significant change from baseline for Week 3 and Week 4 as seen in Table 4. A repeated measures ANOVA was completed to analyze MIP across time in the Sham Group as well. The results of this
analysis revealed a significant difference in mean MIP measures from baseline over 4-weeks of training, $F(4)=7.308$, $p=.002$. Simple contrasts were used to determine the significance of change from baseline at each training week. The analysis revealed a significant change from baseline for Week 4 as seen in Table 5.

Table 4

*Simple Contrasts of Mean MIP at Each Training Week with Baseline Values*  
*(Experimental Group)*

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1 vs baseline</td>
<td>8.937</td>
<td>.040</td>
</tr>
<tr>
<td>Week 2 vs baseline</td>
<td>12.238</td>
<td>.025</td>
</tr>
<tr>
<td>Week 3 vs baseline</td>
<td>30.416</td>
<td>.005*</td>
</tr>
<tr>
<td>Week 4 vs baseline</td>
<td>34.053</td>
<td>.004*</td>
</tr>
</tbody>
</table>

Note. *A Bonferoni adjustment was completed (.05/4=.0125).

Table 5

*Simple Contrasts of Mean MIP at Each Training Week with Baseline Values (Sham Group)*

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1 vs baseline</td>
<td>.647</td>
<td>.466</td>
</tr>
<tr>
<td>Week 2 vs baseline</td>
<td>7.036</td>
<td>.057</td>
</tr>
<tr>
<td>Week 3 vs baseline</td>
<td>6.919</td>
<td>.058</td>
</tr>
<tr>
<td>Week 4 vs baseline</td>
<td>43.043</td>
<td>.003</td>
</tr>
</tbody>
</table>

Note. *A Bonferoni adjustment was completed (.05/4=.0125).*
Research Hypothesis 2

Perceived dyspnea during a 9-minute simultaneous exercise and speech task will decrease following a 4-week IMST program at 75% of the participant’s MIP. The change will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

The mean perceived dyspnea ratings pre-and post-IMST during a 9-minute simultaneous speech and exercise task for both the Experimental Group and the Sham Group are displayed in Table 6 and Figure 4.

Table 6
Mean Perceived Dyspnea Ratings During the Simultaneous Exercise and Speech Task

<table>
<thead>
<tr>
<th></th>
<th>Pre-Training</th>
<th>Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Experimental Group</strong> (N=5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 minutes</td>
<td>2.2</td>
<td>.84</td>
</tr>
<tr>
<td>3 minutes</td>
<td>3.8</td>
<td>1.30</td>
</tr>
<tr>
<td>6 minutes</td>
<td>4.5</td>
<td>1.50</td>
</tr>
<tr>
<td>9 minutes</td>
<td>5.2</td>
<td>1.92</td>
</tr>
<tr>
<td><strong>Sham Group</strong> (N=5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 minutes</td>
<td>3</td>
<td>.71</td>
</tr>
<tr>
<td>3 minutes</td>
<td>4.3</td>
<td>.45</td>
</tr>
<tr>
<td>6 minutes</td>
<td>4.8</td>
<td>.84</td>
</tr>
<tr>
<td>9 minutes</td>
<td>5.2</td>
<td>1.79</td>
</tr>
</tbody>
</table>
Note. 0 minutes, 3 minutes, 6 minutes and 9 minutes represent the duration of the simultaneous exercise and speaking task. Dyspnea ratings were taking at minute 0, during 15 second breaks at minute 3 and 6, and then at the end of the task at minute 9.

Figure 4
Mean Perceived Dyspnea Ratings Pre-and Post-Training by Group

The values used to complete the following analyses were the mean perceived dyspnea data points from the time periods 0 minutes to 9 minutes for participants in each group (Experimental and Sham). A repeated measures ANOVA revealed a significant main effect for the within subject factor of time (pre-and post-training), $F(1, 8) = 16.320$, $p = .004$. However, the time by group (Experimental and Sham) interaction was not significant, $F(1, 8) = .243$, $p = .635$. As a follow-up, paired sample t-test was used to analyze the measures of perceived dyspnea for the Experimental Group pre-and post-training. While this analysis was conducted with a small number of participants it remains important in order to determine the significance of the IMST program for the Experimental Group. The analysis revealed no significant change across time, $t(4)=1.994$, $p=.117$. 
Research Hypothesis 3

Recovery time (defined by a return of minute ventilation to a level within 15% of baseline) will decrease after a 9-minute simultaneous exercise and speech task following a 4-week IMST program at 75% of the participant’s MIP. The change will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

The total recovery time once Ve reached 15% of baseline following the completion of the 9-minute simultaneous exercise and speech task pre-and post-IMST is displayed in Table 7 and Figure 5.

Table 7
Mean Total Recovery Time (in seconds) by Group

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group (N=5)</th>
<th>Sham Group (N=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M   SD</td>
<td>M   SD</td>
</tr>
<tr>
<td>Pre-Training</td>
<td>413  110</td>
<td>413  146.89</td>
</tr>
<tr>
<td>Post-Training</td>
<td>382  76</td>
<td>423  144</td>
</tr>
</tbody>
</table>
Figure 5
Total Recovery Time by Ve within 15% of Baseline Value

Note. Pre-training recovery data for one of the participants in the Sham Group was included in the analysis even though the test was terminated when Ve was within 17% of baseline. All other 9 participants had a Ve value within 15% of baseline when the test was terminated.

A repeated measures ANOVA revealed that main effect for time (pre- and post-training) was not significant, $F(1,8) = .004, p = .950$. The time by group (Experimental and Sham) interaction was also not significant, $F(1,8) = .179, p = .683$. A paired-sample t-test was used to analyze the total recovery time for the Experimental Group pre-and post-training. While this analysis was conducted with a small number of participants it remains important in order to determine the significance of the IMST program for the Experimental Group. The analysis revealed no significant change across time, $t(4)=.877, p=.430$.

Secondary Analysis: Ventilation

While the investigation of changes in ventilation was not one of the major research questions for this project, it was felt that examining these change would be of interest and potentially provide information that would assist in a better understanding of
changes in dyspnea and recovery time. During the task the participants’ ventilation was recorded for analysis as detailed in the methods section. Each participant’s breath-by-breath volume and frequency were measured across the entire 9-minute simultaneous exercise and speech task. Based on those values the participant’s tidal volume (VT), breathes-per-minute (BPM), and overall ventilation (Ve) were calculated (data were averaged across 15 second periods). Ventilation measures, including VT, BPM and Ve, during the 9-minute simultaneous exercise and speech task pre-and post-training are displayed in Table 8. Mean Ve changes during a simultaneous exercise and speech task pre-and post-training are displayed in Figure 6. The mean measures for the variables were calculated from the mean of all data points (15 second averages) recorded during the 9-minute simultaneous exercise and speech task for each group (Experimental and Sham).

Table 8

*Mean Ventilation Changes During Simultaneous Exercise and Speech Task Pre-and Post-Training*

<table>
<thead>
<tr>
<th></th>
<th>Pre-Training</th>
<th>Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Experimental Group (N=5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT (L)</td>
<td>1.64</td>
<td>.35</td>
</tr>
<tr>
<td>BPM</td>
<td>26.42</td>
<td>4.08</td>
</tr>
<tr>
<td>Ve (L/min)</td>
<td>42.59</td>
<td>8.20</td>
</tr>
<tr>
<td>Sham Group (N=5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT (L)</td>
<td>2.05</td>
<td>.37</td>
</tr>
<tr>
<td>BPM</td>
<td>20.16</td>
<td>2.07</td>
</tr>
<tr>
<td>Ve (L/min)</td>
<td>40.76</td>
<td>4.24</td>
</tr>
</tbody>
</table>
In order to determine if there was a significant difference in ventilation between pre-and post-training simultaneous exercise and speech tasks and whether or not the difference was significant between groups (Experimental and Sham), a repeated measures ANOVA with time (pre/post) as the within-subjects factor and group as the between-subject factor was performed. This analysis revealed that the main effect for time was not significant for Ve during the 9-minute simultaneous exercise and speech task, $F(1,8) = 261.934, p = .118$. The time by group (Experimental and Sham) interaction was not significant, $F(1,8) = 215.682, p = .150$. 
CHAPTER V
Discussion

Background

Interpretation of Results by Research Hypothesis

Research hypothesis 1. **Mean maximum inspiratory pressure (MIP)** will increase from baseline following a 4-week IMST program at 75% of the participant’s MIP. The change from baseline will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

The results of the analysis revealed that MIP changed significantly over the 4-week IMST program at 75% of MIP for participants in the Experimental group. These results support previous research which has reported increased MIP measures when training at loads of 50 to 80% of MIP (Caine & McConnell, 1998a; Gething Passfield, & Davies, 2004). While not measured directly, it is believed that this change is the result of increased neural adaptations to specific muscles, in this case the inspiratory muscles, which increased the ability of the central nervous system to activate these muscles (Sale, 1988). Due to the length of the IMST program (4 weeks), it is unlikely structural changes, such as an increase in proportion and size of muscle fibers, occurred.

However, surprisingly there was no significant difference in the percent change in MIP over the 4-weeks of training between the Experimental Group which trained at 75% of MIP and the Sham Group which trained at 10% of MIP. This finding was unexpected, since training loads of 15% to 25% of MIP in previous studies with healthy participants revealed no significant changes of MIP measures (Caine & McConnell, 1998b; Volianitis et al., 2001). Several previous studies have reported no significant changes in MIP at those lower training loads. For example, Romer, McConnell and Jones (2001) report a study of healthy athletes in which the participants who trained at 50% of MIP demonstrated a 30% increase post-training, while the control group training at 15% of MIP demonstrated less than a 1% increase.

One highly probable explanation for this training effect is the training instructions given to the participants. The instructions given for the IMST program were identical for Experimental and Sham training groups in order to provide consistency between the
groups for a controlled study. However, during the weekly training meetings it was noted that the participants in the Sham Group were over-training by inspiring exaggerated lung volumes despite the fact that they only needed to overcome 10% of their maximum MIP to achieve the training maneuver. Therefore, it is possible that due to the large inspirations produced during training (larger than an inspiration needed to overcome 10% of maximum MIP), the Sham group participants achieved training effects even at the minimal training load. This training effect for participants in the Sham Group resulted in potential effects for all research hypotheses of the present study. Possible solutions for this confounding variable will be discussed in the future directions section in order to provide increased control for future research.

The inspection of individual data revealed two participants whose changes in MIP adjusted the mean for the group (Experimental or Sham). Specifically, one participant in the Experimental Group demonstrated only an 18% change in MIP, while one participant in the Sham Group demonstrated a 30% increase in MIP. If these subjects were not included in the group analysis, the Experimental Group had a higher percent change in MIP across a 4-week training program. This change within the Experimental Group provides motivation to continue this area of study and validates the need for a larger sample size.

Research hypothesis 2. Perceived dyspnea during a 9-minute simultaneous exercise and speech task will decrease following a 4-week IMST program at 75% of the participant’s MIP. The change will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

The results of the analysis revealed that ratings of perceived dyspnea during a 9-minute simultaneous exercise and speech task decreased following training for all participants (Experimental and Sham) as indicated by a significant main effect for time (pre to post-training). However, this decrease was not significant by group shown by the lack of significance in the group by time interaction. Therefore, the decrease in perceived dyspnea ratings was not significantly different between the two groups (Experimental and Sham). The hypothesis regarding this parameter indicated that the decrease in dyspnea would be greater in the Experimental Group due to the expected increases in MIP. It is
possible that this lack of significance is due to the instructions given to the participants in the Sham group and the larger than expected training effect in this group.

Further analysis to just examine the change in dyspnea in the Experimental group revealed no significant difference over time despite a 1.2 rating (scale was 0 to 10) decrease from pre to post-training. It should be noted that the examination completed with the Experimental group only was done with 5 participants and therefore, had lowered statistical power. Despite the lack of significance, this change in dyspnea should be examined further with a larger number of participants.

This slight decrease in dyspnea may be the result of several possible factors. The first is that this change was the result of increased neural adaptations to specific muscles, in this case the inspiratory muscles, which increased the ability of the central nervous system to activate these muscles, thereby decreasing the fatigue of those muscles during the simultaneous exercise and speech task (Sale, 1988). The second possibility is that due to the improved efficiency of respiratory muscles, specifically the muscles of inspiration, blood flow was redirected to the limb locomotor muscles during the simultaneous exercise and speech task, thereby decreasing the fatigue of the respiratory muscles (Romer & Dempsey, 2002). The third possibility is that increased muscular strength resulted in improved function of the muscles to perform work, thus delaying fatigue (El-Manshawi, Killian, Summers, & Jones, 1986), decreasing the individual’s estimation of effort at a specific work load (Gandevia, Killian, & Campbell, 1981), and decreasing the motor command of the muscles at a specific muscular tension (Redline, Gottfried, & Altose, 1991).

Yet, it is possible that even with a larger number of participants in the study, the change from pre-to post-training within the Experimental Group and compared to a Sham Group may not reach significance. This would be likely if the degree of change required in the contractile ability of the inspiratory muscles, as discussed in the previous paragraph, was not observed after only 4 weeks of training. In this case, the short length of the training period may not allow the mechanisms which decrease the perception of dyspnea to take effect.
Research hypothesis 3. Recovery time (defined by a return of minute ventilation to a level within 15% of baseline) will decrease after a 9-minute simultaneous exercise and speech task following a 4-week IMST program at 75% of the participant’s MIP. The change will be significantly greater than a group of participants completing the training at 10% of their MIP (sham training).

The total recovery time (as defined by a return of minute ventilation to a level within 15% of baseline) decreased by 31 seconds for participants in the Experimental Group following the 9-minute exercise and speech task. Although the Sham Group demonstrated an increase of 10 seconds for total recovery time following a 9-minute simultaneous exercise and speech task post-training compared to pre-training, the difference between the groups in recovery time failed to reach statistical significance.

The decrease in the Experimental Group of total recovery time is consistent with previous research, which found a 6.9% decrease in recovery time for athletes following a 6-week IMST program (Romer, McConnell, & Jones, 2002). This decrease in total recovery time may be due to the overall improved muscular strength, specifically the inspiratory muscles as a result of neural adaptations (Sale, 1988), or the decreased fatigue of the respiratory muscles due to a redirection of blood flow to the limb locomotor muscles (Romer & Dempsey, 2002).

While a separate analysis of just the recovery time for the Experimental Group failed to reach statistical significance as well, the decrease of 31 seconds may be physiologically significant for certain individuals. For instance, individuals with a compromised respiratory mechanism, due to disease or underlying conditions, confronted with functional limitations daily may find a difference of 31 seconds to be enabling. Additionally, individuals whose occupation requires efficiency and productivity may find 31 seconds to be crucial for the completion of work tasks.

It is possible that the lack of significance for recovery time between groups (Experimental and Sham) is due to the instructions given to the participants in the Sham group, which resulted in a larger than expected training effect in this group. Even if future analysis reveals no significant change for the Experimental Group, it would be important to remove this confounding variable in order to determine any significant changes between groups.
Secondary analysis: Ventilation

The results of the analysis revealed no significant difference in Ve over the 9-minute simultaneous exercise and speech task. Furthermore, there was no significant difference in Ve during the task for the groups (Experimental and Sham). Visual inspection of the graph reveals an increase in Ve post-training for the Sham Group. This increase was due to one participant whose mean Ve across the 9-minute task drastically increased post-training compared to pre-training (33L/m to 73L/m). It is unknown why this increase occurred. It may be that the baseline recording during the pre-training testing was not reflective of the participant’s maximum ability. Several factors can potentially impact this test, such as sleep and diet. In summary, due to the results of the analysis of Ve during the 9-minute simultaneous exercise and speech task, this information will not assist with understanding perceived dyspnea and recovery time.

One important comment is required to conclude the discussion of the secondary analyses regarding this study. While carrying out the methodology of this study, the question arose whether Ve or VO2 represented recovery from the task most accurately. In order to provide comparative analysis during the recovery period, the return to baseline of both Ve and VO2 were recorded. Ventilation is a measure representing the work being done to achieve a certain VO2, while VO2 is a measure of the O2 consumed during work. As both parameters represent work being done towards recovery, it is expected that both measures would return to baseline following a similar timeline. Specific analysis of VO2 was considered once all participants had finished the study, causing this analysis to be less developed and incomplete. Therefore, in determining recovery time within 15% of VO2, two participant’s tests were terminated within 25% and 33% of baseline. As a result, comparisons between Ve and VO2 recovery times were not possible using this data. Further analysis of the total recovery time based on Ve versus VO2 could provide more detailed information about the most accurate measure of recovery. Possible solutions to this problem will be discussed in the future directions section.

Limitations

One notable limitation of this study was the small number of participants (5 Experimental Group, 5 Sham Group). This limited number of participants greatly reduces the power for between group comparisons for all research hypotheses.
Specifically, MIP measure changes over the 4-week IMST program and post-training measures of perceived dyspnea and recovery time.

A second notable limitation was the instructions given to the participants during the 4-week IMST program. The Experimental Group and the Sham Group were given identical instructions in order to provide consistency between the groups for a controlled study. However, during the weekly training meetings it was noted that the participants in the Sham Group were over-training by inspiring exaggerated lung volumes despite the fact that they only needed to overcome 10% of their maximum MIP to achieve the training maneuver. Therefore, it is possible that due to the large inspirations produced during training (larger than an inspiration needed to overcome 10% of maximum MIP), the Sham group participants achieved training effects even at the minimal training load. This training effect for participants in the Sham Group resulted in potential effects for all research hypotheses of the present study. Specifically, MIP measure changes over the 4-week IMST program and post-training measures of perceived dyspnea and recovery time.

Future Research

It would be beneficial to conduct future studies using the same testing procedures with a larger number of participants and three key modifications to the protocol. This would allow for additional analysis of MIP, perceived ratings of dyspnea and recovery time pre-and post-training. The first change would be generating a unique set of directions for the Sham Group training at 10% of MIP, in order for participants to complete optimal training at this minimal training load. The new directions should focus on preventing the participants from inspiring exaggerated lung volumes when completing the training, by instructing the participants to only inspire to a lung volume that would generate the minimum amount of negative pressure required during the training maneuver.

The second change would be implementing an orientation day before the actual testing days begin, in order to familiarize the participants with the equipment and procedures of the study, due to the unique equipment and complex protocol the participants encounter during this portion of the study. On this orientation day, the participants would become familiarized with all equipment and procedures to reduce the learning effect, once the actual testing days have begun. The results of the present study
revealed a change in perceived dyspnea ratings for the Experimental Group; however, the Sham Group experienced a similar change in perceived dyspnea ratings as well pre-and post-training. It is unknown whether this change was due to the small sample size or the training effect in the Sham Group. However, if there was indeed no change in this variable between groups (Experimental and Sham), the change pre-and post-training may be due to the comfort level with the testing equipment, procedures and task. It is important to note, however, that minimal changes in VO2 max were observed pre-and post-training for both groups (Experimental=.7% change and Sham=1.5% change), indicating that participants were working at similar levels, which were expected to be their maximum performance during both pre- and post-training tests.

Additional control would be added to the study design with specific changes to the groups to which the participants are assigned. The participants would complete a control, sham training and IMST training period each lasting 4 weeks. Pre-and post-testing would be completed at each period of the study, while MIP would be measured weekly during the control and training periods. The control period would consist of passing out the IMST trainer and reading materials related to muscle training would be provided at the weekly meetings. The sham training would consist of training at 10% of MIP and the IMST training would consist of training at 75% of MIP. The changes would create a more solid design and powerful analysis. Each participant would serve as his or her own control group and the three training periods would provide multiple baseline measures to compare for data analysis.

The third change would be to lengthen the recovery time following the 9-minute simultaneous exercise and speech task; specifically, the sitting recovery. In the present study, the early termination of the test for three participants impacted the ability to perform statistical analysis and a comparison between Ve and VO2. One possible solution to increase the length of the sitting recovery time would be to terminate the test once participants have stabilized for 2-minutes at 15% of baseline measures, thereby reducing the opportunity for error.

In addition to the research hypotheses of this study, it would be interesting to analyze Ve during the 9-minute simultaneous exercise and speech task with more detail. The examination of ventilation in the present study was secondary to the main research
hypotheses, and therefore fairly narrow in the scope of the analysis. The present study analyzed Ve using the average Ve over the entire 9-minute task. Analysis would include specific analysis of Ve during reading segments of the task (minute 0, minute 3 and minute 6), Ve during the 15 second breaks, and Ve during recovery periods. This detailed analysis would determine if there are changes pre-and post-training by specific time period.

Furthermore, this research study analyzed objective or physiological recovery time only. Previous research has reported a difference between physiologic and subjective recovery, with participants having faster subjective recovery compared with physiologic recovery (Wu, Hsu, & Chen, 2005). It would be interesting to analyze subjective recovery time, which could be defined by perception of dyspnea, during the sitting recovery, in order to determine the specific differences between physiologic and subjective recovery during slow recovery periods and the impact of a 4-week IMST program on subjective recovery.

The clinical implications of this research include a non-invasive method of training which increases inspiratory muscle strength, thus potentially decreasing the perceived dyspnea and recovery time that results from occupational or daily living tasks which require simultaneous exercise and speech. Therefore, it would be interesting for future studies to include participants from these populations in the study and to have these participants subjectively report on occupational or daily living changes that occur throughout the study using a questionnaire or journal. Individuals with a compromised respiratory mechanism, due to disease or underlying conditions, completing tasks of daily living confronted with functional limitations would experience an improved quality of life with the reduction of the impact of dyspnea and recovery time. Individuals whose occupation requires efficiency and productivity would experience enhanced job performance due to a reduction of dyspnea and recovery time. The use of IMST is of importance for these populations and therefore this area of research should continue.
References


speech. *Respiration Physiology, 46*, 137-147.


APPENDIXES

Appendix A

Health Questionnaire

1) List the major surgeries you have had within the last 5 years.

2) Are you being treated right now for any medical conditions? If so, what?

3) Are you bothered by any of the following? Please indicate with a check mark.
   - __ Hoarseness
   - __ Fatigue (voice tires or changes quality after speaking for a short period of time)
   - __ Loudness (either too high or too low during speaking)
   - __ Breathiness
   - __ Tickling or choking sensation
   - __ Pain in the throat
   - __ Pitch breaks
   - __ Voice shuts off briefly

4) Have you had a recent cold or flu? Y/N

5) Do you have allergies? Y/N

6) Have you have smoked tobacco products or other drugs? Y/N
   If you used to smoke, for how many years and when did you stop?

7) Past medical history (Have you had a medical history for any of the following? Circle as many as apply.)
   - High blood pressure
   - Cardiac problems
   - Neurological problems
   - History of cancer
   - Asthma
   - Respiratory disease
   - Immune system disorder
Appendix B

Reading Passages

The Rainbow Passage

When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

The Grandfather Passage

You wish to know all about my grandfather. Well, he is nearly 93 years old, yet he still thinks as swiftly as ever. He dresses himself in an ancient black frock coat, usually missing several buttons. A long beard clings to his chin, giving those who observe him a pronounced feeling of the utmost respect. When he speaks, his voice is just a bit cracked and quivers a bit. Twice each day, he plays skillfully and with zest upon a small organ. Except in the winter, when the snow or ice prevents, he slowly takes a short walk in the open air each day. We have often urged him to walk more and smoke less, but he always answers, “Banana Oil.” Grandfather likes to be modern in his language.

California Passage

California is a unique state. It is one of the few states that has all the geographical features found in the rest of the country, including deserts, forests, mountain ranges, and beaches. Its beaches draw thousands and thousands of people each year, particularly
during the summer months when the sun is shining, the skies are blue, and the ocean is warm enough to swim in. Surfers are often in the water by daybreak. Of course there are many other things to do besides surfing, such as sailing, swimming, water skiing, kite flying, and sun bathing. In the winter the mountains of California are favorite vacation spots. Here snow skiing is the sport. There are many places in California to snow ski, but the largest and most popular is Mammoth Mountain. Because of its popularity the property surrounding the Mammoth Ski Resort is extremely expensive. Unfortunately, the threat of earthquakes in this area is very high. In fact, earthquakes are common occurrences in many parts of California. Because of this, there are people who are afraid that someday a large piece of the state will fall into the Pacific Ocean. The possibility of a serious earthquake such as the one that demolished San Francisco in 1906 frightens some people enough that they choose not to visit California just for that reason.

Zoo Passage

Look at this book with us. It’s a story about a zoo. That is where bears go. Today it’s very cold out of doors, but we see a cloud overhead that’s a pretty, white fluffy shape. We hear that straw covers the floor of cages to keep the chill away; yet a deer walks through the trees with her head high. They feed seeds to birds so they’re able to fly.
Appendix C

BORG Scale

Please rate your **breathing effort** using this scale. 0 indicates no difficulty at all and 10 the maximum tolerable level

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Nothing at all</td>
</tr>
<tr>
<td>0.5</td>
<td>Very, very slight</td>
</tr>
<tr>
<td>1</td>
<td>Very slight</td>
</tr>
<tr>
<td>2</td>
<td>Slight</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Somewhat severe</td>
</tr>
<tr>
<td>5</td>
<td>Severe</td>
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<td>6</td>
<td></td>
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<tr>
<td>7</td>
<td>Very severe</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Very, very severe (almost maximal)</td>
</tr>
<tr>
<td>10</td>
<td>Maximal</td>
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</tbody>
</table>
Appendix D

Instructions for Inspiratory Muscle Strength Training

The most important number to remember throughout this training period is the number 5. You will complete this training program 5 days per week. You will complete 5 sets of the exercises with 5 repetitions each time you complete your training. You have been given a respiratory trainer to complete your training at home. You will use the same training for the entire time that you are participating in this study.

1. Place the nose clip on your nose.
2. Breathe out as much air as you possibly can, and place your mouth on the mouthpiece.
3. As soon as the mouth piece is in your mouth, breathe out as much air as you can.
   • Keep a tight seal with your mouth around the mouth piece;
   • When the inspiratory force is strong enough to open the valve, you will hear a rush of air move through the device.
4. Repeat this inspiration exercise 5 times (steps 1-4), resting for 10 -30 seconds between each inspiration.
5. When you have finished all 5 inspirations, rest for at least 30 seconds (you have completed one set).
6. After you have rested, complete steps 1-5 again until you have completed all 5 sets.
7. On your training log, record the date and time you completed the exercises.
8. You will complete the training program 5 times per week.
9. At the end of the training week you will meet with Susan Baker during which your maximum inspiratory strength will be measured and your trainer will be reset.
Appendix E

Training Log

Start date: __________

Trainer Setting: __________ (If trainer moves off this mark, adjust back to the number)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>SET 1 (5 breaths)</th>
<th>SET 2 (5 breaths)</th>
<th>SET 3 (5 breaths)</th>
<th>SET 4 (5 breaths)</th>
<th>SET 5 (5 breaths)</th>
</tr>
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</tbody>
</table>

Next Appointment: Date ________ Time ________