ABSTRACT

THE EFFECTS OF AN INSPIRATORY MUSCLE TRAINING PROGRAM ON MAXIMAL INSPIRATORY PRESSURE AND SWIMMING PERFORMANCE

The purpose of this study was to determine whether 6 weeks of inspiratory muscle training would exhibit improvements in maximal inspiratory pressure (MIP), swimming performance, and other respiratory measures. Thus far, studies investigating the effects of respiratory muscle training have yielded conflicting results regarding their application in improving sports performance. A 6-week inspiratory muscle training program was applied to master swimming subjects, using the POWERbreathe® training device. Pre and posttraining evaluations of maximal inspiratory pressure were assessed, this being an indicator of inspiratory muscle strength. A 200-yard swim trial was also performed pre and posttraining to assess changes in swimming performance. To determine whether there were significant improvements made to the previously mentioned variables, gain scores were calculated by subtracting the posttest measures from the pretest measures. A one way ANOVA was then run separately for each of the variables. Following statistical analysis, there was no significant difference in any of the six variables measured. These results may be due to the short nature of the training period (6 weeks), as well as the age of the population that was used.

Amanda Stetler
May 2010
THE EFFECTS OF AN INSPIRATORY MUSCLE TRAINING PROGRAM ON MAXIMAL INSPIRATORY PRESSURE AND SWIMMING PERFORMANCE

by

Amanda Stetler

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Kinesiology in the College of Health and Human Services California State University, Fresno May 2010
APPROVED

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Chapter 1

INTRODUCTION

Recently in the 2008 summer Olympic Games, the world witnessed gold medals being won and lost by minute margins. Michael Phelps triumphed over Serbian swimmer Milorad Cavic to win the gold medal in the 100-meter butterfly by 0.001 of a second. In a similar situation, American swimmer Dara Torres lost the 50-meter freestyle to Britta Steffen of Germany by 0.001 of a second. These races show that, when it comes to winning and losing in athletic competition, every portion of a second counts. Athletes train endlessly to ensure that they are as prepared as possible to give 100% effort in competition. This brings to light the option of a relatively new form of training that specifically engages the muscles of the respiratory system in order to increase levels of fitness and performance.

Respiratory muscle training is a method of resistance training using a generic device that applies resistive loading in order to improve the strength of the respiratory muscles (Sheel, 2002). This training method has been tested in numerous studies within the past few decades, yet the outcomes following this training have yielded conflicting results. Some studies have shown significant improvements of time-trial performances in competitive cyclists following a period of respiratory training, while these improvements were not seen in the control group that underwent no respiratory training (Holm, Sattler, & Fregosi, 2004). Yet a study by Sonetti, Wetter, and Dempsy (2001) concluded that respiratory muscle training had no effect on the performance of trained cyclists when compared to their placebo group. Due to the conflicting nature of these
results, further investigation of the effectiveness of respiratory training is necessary before a definitive conclusion can be made.

**Purpose Statement**

The purpose of this research study was to determine whether 6 weeks of regular inspiratory muscle training would exhibit improvements in maximal inspiratory pressure, various respiratory measures, and swimming performance times within master level swimmers.

**Significance of the Study**

This study was significant because the results have contributed to further clarifying whether or not respiratory muscle training has a positive effect on swimming performance. Studies thus far have been conflicting on the outcome of respiratory training on swimming performance. The goal in the present investigation was to determine the effect of inspiratory training has on swimming performance.

**Research Questions**

The research questions listed below were investigated during the proposed study:

1. Will 6 weeks of regular inspiratory training result in improvements in maximal inspiratory pressure?
2. Will 6 weeks of regular inspiratory training result in an improvement in swimming performance times within master level swimmers?
3. Will 6 weeks of regular inspiratory training result in improvements in Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second (FEV1.0), the
ratio of FVC to FEV\textsubscript{1.0}, and Maximal Volitional Ventilation in 15 seconds (MVV\textsubscript{15})?

**Hypotheses**

The following experiment was tested based upon the following two research hypotheses:

Six weeks of inspiratory muscle training will result in an increase in maximal inspiratory pressure.

Six weeks of inspiratory muscle training will also result in an increase in swimming performance times.

Six weeks of inspiratory muscle training will also result in an increase in spirometry measurements (FVC, FEV\textsubscript{1.0}, FEV\textsubscript{1.0}/FVC, MVV\textsubscript{15}).

**Delimitations**

For this present study, all participants were over 18 years of age. All subjects were athletes who regularly engaged in structured swim training. All subjects were free, to their knowledge, of respiratory disease, specifically asthma, COPD, and emphysema. Participants were given a specific inspiratory training device (POWERbreathe\textsuperscript{®} training device) to use for the 6 weeks, and only inspiratory training, as opposed to expiratory training, was performed.

**Limitations**

One limitation for this study was that the training was performed over a limited time frame of 6 weeks. A final limitation is that all measurements are volitional, and require maximal effort from the participant, which cannot always be guaranteed to occur.
Definition of Terms

Inspiratory Muscles: Diaphragm, external intercostals, sternocleidomastoid, and scalene muscles.

Inspiratory Muscle Training: A resistive loading training program that consists of loads ranging from 15% - 80% of maximal inspiratory pressure applied three to six times per week to the respiratory musculature system (Sheel, 2002).

Master Swimmer: A individual 18 years or old who regularly trains as a part of the United States Masters Swimming organization.

Maximal Inspiratory Pressure (MIP): The maximum inspiratory pressure is the highest atmospheric pressure developed during inspiration against an occluded airway (Black & Hyatt, 1969). Maximal Inspiratory Pressure has been determined to reflect the strength/weaknesses of the respiratory muscles (Black & Hyatt, 1969; Sheel, 2002).

Powerbreathe® Training Device: A hand held inspiratory muscle trainer.

United States Master Swimming (USMS) Organization: National organization that provides organized workouts, competitions, clinics, and coaching for adults who want to improve performance in triathlons, swimming competitions, and fitness levels.
There has been contradictory evidence surrounding whether respiratory muscle training causes an increase in performance among healthy individuals and athletes of different backgrounds and sports. Many researchers have found no significant changes in healthy, active individuals that have undergone periods of respiratory training (Mickleborough, Stager, Chatham, & Lindley, 2008; Sonetti et al., 2001). Others have seen significant improvements in the performance of athletes and in measurements such as maximal inspiratory pressure, which is a common indicator of respiratory muscle strength or weakness (Black & Hyatt, 1969; Ratnovsky, Elad, & Halpern, 2008). Respiratory muscle training has become a relatively common method of treatment for patients suffering from respiratory and neurological diseases like chronic obstructive pulmonary disease (COPD), and cystic fibrosis (Ratnovsky et al., 2008). Yet, no unequivocal conclusions regarding the effectiveness of respiratory training have been reached in the medical community. Several different methods and protocols have been used to come to these separate conclusions, possibly explaining the varying results. Thus, use of respiratory muscle training remains a controversial method of training when used to improve athletic and exercise performance.

Respiratory Mechanics

To properly understand the use of respiratory muscle training and the research surrounding these findings, one must first understand the mechanics behind the respiratory muscles. The muscles used for inspiration are the
diaphragm, the external intercostals, the sternocleidomastoid, and the scalene muscles (Ratnovsky et al., 2008). During rest, diaphragm contraction is responsible for up to 50% of inspiratory volume change, and the rest of the work is taken up by the inspiratory accessory muscles (Sheel, 2002). During exercise the diaphragm is responsible for significantly more of the muscular work during inspiration, thus receiving higher amounts of cardiac output and experiencing greater amounts of muscular fatigue during exercise. The muscles used primarily for expiration are the internal intercostals, and the four muscles that make up the abdominal wall (Ratnovsky et al., 2008). At rest, expiration is a passive activity in which the elastic energy developed within the lung and chest wall simply recoils, without assistance of the internal intercostals, the external obliques, the transverse abdomis, or the rectus abdomis (Reid, Geddes, Brooks, O’Brien, & Crowe, 2004). This changes during exercise, when the muscles responsible for expiration are required to assist in a forceful exhalation in order to return lung volume to baseline levels. As the human body engages in an exercise bout, minute ventilation and the frequency of breathing increases. The respiratory muscles play a large part in changing tidal volume, respiratory timing, inspiratory and expiratory flow rates, and end-inspiratory/expiratory volumes during exercise. During low-intensity exercise, the increase of minute ventilation is due to an increase in tidal volume and frequency of breathing. Tidal volume is known to plateau around 60% of vital capacity; thus as exercise intensity increases, minute ventilation is increased simply due to increased frequency of breathing. Tidal volume increases are due to a decrease in end expiratory volume, and an increase in end inspiratory lung volume (Sheel, 2002). These changes in lung volume greatly rely on the inspiratory and expiratory muscles, thus requiring a large amount of work to be performed by this muscle group, especially during high intensity exercise. It is up
to the respiratory muscles to properly match the necessary pulmonary reaction to the needs of the cardiovascular and metabolic systems, during rest and exercise. At rest, the oxygen cost required for breathing is quite minimal. It only takes up a small amount of total resting energy expenditure, with approximately 0.5 - 1.0 ml L⁻¹. During high intensity exercise, pulmonary ventilation increases, with oxygen uptake of the respiratory muscles reaching approximately 8 ml L⁻¹ taking up a much larger portion of total energy expenditure (Astrand, Rodahl, Dahl, & Strømme, 2003). If for any reason the respiratory muscles are unable to match the needs of the pulmonary and cardiovascular systems, then gas transport and proper gas exchange between the blood and the alveoli can become compromised. Thus, it becomes extremely important for the respiratory muscles to always be properly prepared to match the necessary pulmonary needs. In situations where respiratory muscles fatigue, this can jeopardize the muscles’ ability to respond to pulmonary and metabolic demands. These factors have the potential of limiting exercise tolerance and adherence in diseased populations, as well contributing as a possible limiting factor in healthy populations as well.

**Respiratory Muscle Weakness During Exercise**

Due to the assistance of the inspiratory muscles during exercise, there is a resulting fatigue of the diaphragm that occurs during high intensity activities or during prolonged endurance exercise (Johnson, Aaron, Babcock, & Dempsey, 1996). The diaphragm is a muscle that was long thought to be highly resistant to fatigue due to the dense capillarization and oxidative properties of the muscle. However, the diaphragm has been found to fatigue during periods of high intensity exercise (Johnson, Babcock, Suman, & Dempsey, 1993). The fatiguing of the diaphragm has been hypothesized to be caused by the redistribution of blood flow
during high intensity exercise to the working skeletal muscles and away from the
diaphragm, thus denying the diaphragm of the much needed oxygen during this
type of exercise. Another hypothesis is that there is less blood to remove
metabolic byproducts away from the diaphragm, which may inhibit muscle
contraction. The fatigue experienced in the diaphragm and accessory muscles can
prevent adequate ventilation, as displayed by exercise-limiting symptoms like
shortness of breath or increased levels of fatigue. Inspiratory training is believed
by some to delay diaphragm fatigue, and consequently improve the endurance
capacity of the muscle (Wells, Plyley, Thomas, Goodman, & Duffin, 2005).

Respiratory Muscle Strength

There are several different methods used to assess respiratory muscle
strength. Evaluating an individual’s maximal inspiratory or expiratory pressure
are two such methods. Maximal inspiratory pressure readings can be taken using
several different protocols. Black and Hyatt (1969) originally assessed maximal
inspiratory and expiratory pressure using two diaphragm gauges mounted on a
metal bar connected to a metal cylinder. The gauges were connected to a generic
pressure tap at the distal end of the cylinder by plastic tubing. The cylinder had a
small opening that was designed to prevent the facial muscles from contributing
significantly to the pressure measurements. On the cylinder, a mouthpiece was
fitted, and the gauges were then calibrated using a pressure transducer. A digital
device has also been created by MicroMedical Co.® that is designed to evaluate
maximal inspiratory and expiratory pressure. MIP measurements have been found
to be fairly accurate and consistent in evaluating respiratory muscle strength, and
have been used as the form of assessment for respiratory muscle strength in
numerous studies (Gregory, Michael, Scott, Len, & James, 2005; Griffiths,

Another common method used to evaluate respiratory muscle strength is through bilateral electrical phrenic nerve stimulation performed to measure twitch transdiaphragmatic pressure. This is a nonvolitional procedure commonly used in patients who are unwilling or unable to take part in a volitional form of testing. This method displays accurate and reproducible results, yet subjects often find it difficult to relax during testing, which can alter the PDI measurements (Polkey, Green, & Moxham, 1995). Due to the invasive nature of this procedure, and the discomfort it presents to the subjects participating in the assessment, it is rarely used as a method of respiratory muscle strength assessment.

**Respiratory Muscle Training**

It has been suggested by previous studies that the respiratory system may be a limiting factor in exercise performance. Controversy exists over the use of respiratory muscle training (RMT) as a method of increasing respiratory muscle strength and endurance and thus using it as an ergogenic aid in exercise performance. Respiratory muscle training is defined as a strength training program for both the inspiratory muscles and expiratory muscles. This training has been investigated in both sedentary and active subjects (Boutellier, Buechel, Kundert, & Spengler, 1992; Boutellier & Piwko, 1992). Boutellier et al. did a study using eight healthy trained subjects who underwent 30 minutes of RMT, 5 days a week for 4 weeks. Although subjects failed to see increases in VO2max or anaerobic threshold, they were able to continue cycling at a given speed for a longer duration. Some studies have reported a connection between inspiratory muscle training and increases in maximal inspiratory mouth pressure, thus
concluding that an increase in inspiratory muscle strength has occurred (Gregory et al., 2005; Griffiths et al., 2007). These results directly conflict with the findings of other investigations that found no changes in maximal inspiratory pressure, or in performance values following a period of structured respiratory training (Mickleborough et al., 2008; Sonetti et al., 2001). The discrepant results between different RMT studies may be due to the lack of a standard protocol when engaging in respiratory muscle training. The length and intensity of single training sessions vary from study to study, and the specific duration of training remains inconsistent between different research experiments. Furthermore, there is no one specified device that is used during the training, and so a variety of generic devices have been utilized for different investigations. Due to these incongruities, evaluation of respiratory training is an ongoing process, and one must fully understand what respiratory muscle training is before continuing to evaluate the research surrounding its use.

Respiratory muscle training consists of two different aspects: inspiratory muscle training and expiratory muscle training. Expiratory muscle training incorporates the use of a resistive loading training program using approximately 15-50% maximal expiratory pressure. This training is designed to increase the strength of the internal intercostal muscles and abdominal muscles during exhalation. Studies involving expiratory muscle training have yielded little evidence that training improves maximal expiratory pressure and performance (Griffiths et al., 2007; Wells et al., 2005). Inspiratory muscle training (IMT) is a similar training program that applies loads ranging from 15-80% of the participants’ maximal inspiratory pressure. This training is designed to strengthen the diaphragm and the accessory muscles during inspiratory training. Due to the large contribution of the diaphragm during high intensity exercise, inspiratory
training is assumed to help strengthen the diaphragm, thus delaying fatigue and prolonging exercise (Ratnovsky et al., 2008). This type of training has been the focus of numerous training studies, and has yielded both positive and negative results.

Protocols surrounding the use of respiratory training vary a great deal between studies. The majority of respiratory muscle training studies include a control group, which receives a placebo form of treatment or no treatment at all (Tong et al., 2008). Some studies utilize both a control group and a placebo group, in which the control group receives no treatment, but the placebo group receives a sham form of treatment. It appears an inspiratory training device set to 15% or lower of the individuals’ maximal inspiratory pressure will provide no benefit from the training (Tong et al., 2008).

Respiratory muscle training methods also differ in the frequency and intensity of the loading protocol. Mickleborough et al. (2008) researched the effects of IMT on swimmers with training set at 80% of maximum inspiratory pressure. However, a more common training load has been 50% of both maximum inspiratory pressure and maximum expiratory pressure (Gregory et al., 2005; Griffiths et al., 2007; Johnson, Sharpe, & Brown, 2007; Tong et al., 2008). Other studies have increased intensity throughout the training period. For example, Wells et al. (2005) engaged subjects in IMT with loads at 50% MIP for the first 3 weeks, and then regularly increased the percentage of MIP every 3 weeks until the subjects reached 80% MIP. Frequency of training has also fluctuated from study to study. Depending on the device used, training was recommended as little as one time per day (Hart, Sylvester, Ward, Cramer, & Polkey, 2001), to as many as three times per day (Battaglia, Fulgenzi, Bernucci, Giardini, & Ferrero, 2006). A majority of the studies required 30-40 maximal inspiratory efforts against the
prescribed load during each training session. Training would take place as little as 3 days a week (Mickleborough et al., 2008) or as often as 7 days a week (Griffiths et al., 2007). It appears that studies that incorporated IMT for longer periods and had resistive loads set at higher levels saw larger changes in maximal inspiratory pressure, as opposed to those studies that performed training at lower intensities and for a shorter duration (Sheel, 2002).

The apparatuses used to perform RMT have also varied between studies. One very common device used is the POWERbreathe® inspiratory trainer, which is available to the public and is marketed for health, fitness, and performance. The POWERbreathe® device is designed to specifically focus on the inspiratory muscles. It has been utilized in studies testing inspiratory muscle changes in diseased populations, such as those suffering from chronic obstructive pulmonary disease (COPD) and asthma (Reid et al., 2004) The POWERbreathe® device has also been tested on healthy populations, with specific focus on improving fitness levels in active populations (Hart et al., 2001). It has been used to train a wide variety of athletic groups, such as sprinters (Tong et al., 2008), competitive rowers (Griffiths et al., 2007), swimmers (Gregory et al., 2005), and competitive cyclists (Johnson et al., 2007). Other devices such as the Power Lung® have also been used for training during studies, although not as commonly as the POWERbreathe® device (Gregory et al., 2005; Mickleborough et al., 2008). These devices have also yielded conflicting results following research experimental testing.

**Inspiratory Muscle Training in Diseased Populations**

Respiratory muscle training was first utilized as a means of strengthening respiratory muscle weakness brought on by respiratory and neurological diseases.
Inspiratory muscle training has been used in numerous studies on patients suffering from COPD. As described earlier, COPD often results in inspiratory muscle weakness. Thus, researchers have studied specific inspiratory training in patients diagnosed with COPD (Reid et al., 2004). Battaglia et al. (2006) investigated the effects of 6-month home respiratory muscle training program on COPD symptoms such as dyspnea, hypercapnia, and a decreased tolerance to exercise. Maximal inspiratory/expiratory pressure was assessed, and a 6-minute walking test was performed pre and posttraining. Following training, subjects showed an increase in both inspiratory and expiratory maximal pressures, as well as decreased sensations of breathlessness and an increase to exercise tolerance. It was concluded that the inspiratory muscle strength training had a positive effect on the COPD patients in improving muscle strength and decreasing COPD symptoms. A review by Weiner and McConnell (2005) compared the use of inspiratory muscle training (IMT) to expiratory muscle training (EMT) and the effects this treatment had on COPD symptoms. They concluded that both EMT and IMT can result in increases in respiratory muscle strength and decreased signs of dyspnea and an increase in exercise tolerance. Reid et al. (2004) established guidelines for prescribing IMT for those suffering from COPD. It was recommended to base a training protocol on using conservative inspiratory loads, due to the diaphragm’s affinity to injury resulting from the diseased state of the subject. It was recommended to begin a training program at approximately 50% of MIP or lower, and then gradually increase the resistance, as long as the subject is not suffering from severe dyspnea (Reid et al., 2004). It was also recommended that researchers observe the training to ensure that the subjects participating in IMT are not suffering from injury or delayed onset muscle soreness (DOMS) of the inspiratory muscles. Interviews are recommended to be conducted to
determine if patients are experiencing fatigue or DOMS related symptoms following training. Also, reassessment of maximal inspiratory pressure is recommended in order to determine if a lack of strength or endurance has occurred. Guidelines suggest that resistive loads are low when first beginning a program, and then gradually increase as the patient becomes stronger. Training should at least include 1 to 2 days a week of rest in-between training bouts, again to prevent muscle injury (Reid et al., 2004). These recommendations are specific for patients suffering from COPD, but it’s important to be aware of the observational and interview suggestions that can be applied to IMT in healthy populations.

**Inspiratory Muscle Training in Active Populations**

Due to the potential of the diaphragm to fatigue during high intensity exercise, it has been hypothesized that inspiratory training may strengthen the diaphragm and help prolong exercise and athletic performance. The training itself varies, as mentioned above, and different studies have seen different results using various training protocols. Tong et al. (2008) conducted a study specifically focusing on competitive university level soccer and rugby players, and based performance changes during a 20-meter shuttle run. Participants in this study were instructed to perform 30 maximal inspirations once daily, 6 days a week, for 6 weeks against a resistance of 50% MIP for the experimental group and 15% for the sham training group. Subjects who participated in the experimental group displayed an increase in exercise tolerance and a decrease in perceived exertion. These subjects also saw significant improvement in maximal inspiratory muscle function. These changes were displayed through an increase in maximal inspiratory pressure, maximal rate of pressure development, and maximal
inspiratory flow assessments. Johnson et al. (2007) performed another study focusing on male cyclists who underwent a 6-week training period of inspiratory loading set at 50% maximal inspiratory pressure. The experimental group saw an increase in maximal inspiratory pressure following the period of inspiratory training, yet saw no change in the MIP measurements of the sham group that underwent a period of placebo training. Gregory et al. (2005) reported similar results when testing a group of 34 competitive swimmers between the ages of 15-17 years old who underwent two 6-week periods of training. This particular study evaluated both inspiratory muscle training as well as expiratory muscle training. For the inspiratory training portion, subjects used the POWERbreathe® device with the resistance set at 50% of MIP, and for the expiratory training portion, subjects used the Power Lung® device with the resistance set at 50% of maximal expiratory pressure (MEP). Results following training showed an increase in maximal inspiratory pressure in subjects participating in IMT/EMT, but participants failed to display a significant increase in MEP. Griffiths et al. (2007) reported a significant increase in maximal inspiratory pressure following respiratory training using a POWERbreathe® device. The study population consisted of 17 male competitive rowers who engaged in 4 weeks of IMT twice daily. Following training, the experimental group displayed a significant increase in maximal power output during a 6-minute all out rowing effort. Hawkes et al. (2006) saw an increase in maximal inspiratory pressure following a single session of inspiratory training, yet this study did not evaluate any method of athletic performance.

Other studies have followed similar training methods and protocols, yet have shown no evidence that significant changes have occurred following periods of inspiratory training (Hart et al., 2001; Sonetti et al., 2001; Williams,
Wongsathikun, Boon, & Acevedo, 2002). Furthermore, it has been argued that changes in maximal inspiratory pressure do not necessarily guarantee an increase in exercise performance (Hart et al., 2001). Subjects experienced increases in maximal inspiratory pressure, yet displayed no significant difference in exercise performance values, such as exercise duration and VO$_2$max. Another study involving nine competitive cyclists, who underwent a period of 5 weeks of inspiratory training, 5 days per week using the POWERbreathe device. Maximal inspiratory pressure measurements were taken, and an 8-km cycling time trial was performed to assess performance. Following training, MIP values of the experimental group did not differ significantly from the placebo group. Time trial performance times also did not differ significantly from those of the placebo group. Based on these results, researchers concluded that inspiratory muscle training failed to have a positive effect on cycling performance (Sonetti et al., 2001).

Other studies have brought to light the possibility that some athletic groups may lack the ability to benefit from inspiratory muscle training. This has been argued when dealing with highly trained, competitive swimmers who underwent swim training concurrently with inspiratory training (Mickleborough et al., 2008). Those subjects who took part in both swim training and regular inspiratory training showed no changes over those who participated in only regular swim training. These findings are significant and warrant further investigation into the causes behind the failure in IMT to result in respiratory adaptations.

**Summary**

In conclusion, a large quantity of evidence supports the hypothesis that inspiratory muscle training results in improvements in inspiratory muscle strength.
as measured by maximal inspiratory pressure, yet results are still controversial regarding its effects on improving exercise performance. Due to the varying protocols utilized for training, as well as varying sample sizes being tested, it becomes difficult to determine the effectiveness of respiratory training.
Chapter 3

METHODS

The following chapter discusses the methodology that was used for this investigation. Descriptions of the participants and protocols are described within the following section.

Participants

The participants in this research study included male and female volunteers from Master’s Swim Clubs in Clovis and Fresno, California. All athletes regularly trained under one swim coach. All subjects were informed of the protocol before agreeing to participate. Participants completed an informed consent form (Appendix A), as well as a Health Assessment Questionnaire (Appendix B). Participants also received written instructions to follow during the inspiratory protocol prior to testing (Appendix C). All participants were instructed to maintain a training log, in which they formally recorded weekly physical activity and the date and time they underwent the inspiratory muscle training. The participants were randomly separated into two groups, with 8 in the experimental group and 7 in the control/placebo group. Subjects were all over the age of 18, and had least 8 months of master level swimming instruction prior to participation. Subjects were also all free of known respiratory disease.

Equipment and Instrumentation

Lab testing and respiratory measurements were all taken in the Human Performance Laboratory at California State University, Fresno. A Parvo Medics TrueOne® 2400 Metabolic Measurement System was used to obtain respiratory
function measurements. Spirometry calibration was performed prior to each test. Maximal inspiratory pressure measurements were assessed on each participant using an inspiratory device based upon the premise outlined by Black and Hyatt (1969). The design for this particular measure was a water filled tube adjacent to a yardstick that was used to assess changes in maximal inspiratory pressure, gauged by changes in centimeters of water. The changes in the height of the water within the tube were videotaped and then accurately determined following frame by frame assessment. Participants used the Sports Performance PLUS POWERbreathe® (Southham, Warkwickshire, England) inspiratory device to train the inspiratory muscles.

**Research Design**

The research design for this study was a randomized, single blind, pre-post test design. Subjects were tested prior to the inspiratory muscle training program and again after they fully completed the six week inspiratory muscle training program.

**Experimental Protocol**

The experimental protocol included a 2-day testing period where baseline measurements were determined. These measurements included familiarization trials using the POWERbreathe® inspiratory device, respiratory function measurements, maximal inspiratory pressure assessment, and a 200-yard swim trial. Participants underwent a specific program in which they did 30 maximal inhalations, once a day, 6 days a week, for 6 weeks using the POWERbreathe® inspiratory device. After the 6-week training program, subjects underwent the same pretraining lab and performance measures.
Pretraining, Day 1, Performance Measurements

All participants performed a 200-yard timed swim trial. This swim was completed using the basic freestyle swim stroke. Each swimmer was verbally encouraged during the swim effort. The swim trials took place at Clovis North High School in Clovis, California, and the Fig Garden Pool in Fresno, California.

Pretraining, Day 2, Lab Measurements

Prior to testing, all subjects signed an informed consent form and completed a health history questionnaire. All participants performed the necessary respiratory function measurements from an upright standing position. Participants were asked to refrain from drinking caffeinated beverages 2 hours prior to testing, and all subjects reported compliance with this request. Different respiratory measurements were taken on each subject using a spirometer. FVC, FEV_{1.0}, FEV_{1.0}/FVC, and MVV_{15} were assessed three different times. The average of each effort was calculated and recorded. These measurements were taken prior to inspiratory muscle training as well as during the posttraining period.

MIP was assessed in each subject before the training period as well as after the training period. The measurements were taken from each subject from a standing position. Each subject was required to exhale to residual volume, and then inhale maximally in the period of 1 second. Each subject took part in two familiarization trials before measurements were recorded. Subjects then performed three maximal inhalations with 20 seconds rest in between each bout to prevent hyperventilation. Each maximal inspiratory pressure test was maintained for 1 second. The average of the three maximal inhalations was taken as the subject’s MIP value. Subjects took part in this same procedure following the 6 weeks of inspiratory training.
All subjects took part in a familiarization session with the POWERbreathe® inspiratory device in order to become accustomed with the inspiratory training protocol. This session lasted approximately 5 minutes, and each subject was instructed how to properly follow the training protocol. During this time subjects performed numerous inspiratory efforts to become familiar with the training.

**Inspiratory Training Protocol**

Subjects participated in a 6-week inspiratory muscle training program using the Sports Performance Plus model of the POWERbreathe® inspiratory training device. Subjects were instructed to perform 30 maximal inspirations through the device once a day. A 10-second rest was required between each maximal inspiration to prevent hyperventilation of the subjects. This activity was performed 6 days a week with a rest day once a week. Subjects participating in the experimental group had the resistance load of the device set at approximately 60% of their maximal inspiratory pressure (MIP). This percentage was determined by the resistance being set so that the subject was only able to complete 40-50 maximal inhalations before they reached failure (Sonetti et al., 2001). This set resistance remained for the first 2 weeks of the training period. The resistance was then increased to approximately 70% of their original MIP value during weeks 3 and 4 of the training period, and was then increased again to approximately 80% during weeks 5 and 6. The resistance load was adjusted every 2 weeks by the researcher or the research assistant who was trained in the adjustment protocol. Subjects participating in the placebo training group followed the same protocol, with the exception of the set resistance load on the POWERbreathe® inspiratory training device. The resistance load was set at ~5%
of the individuals’ MIP for the placebo training group for the first 2 weeks. It was then adjusted by the researcher to ~10% MIP for weeks 3 and 4, and again adjusted to ~15% for weeks 5 and 6. Low resistance was set on the device to ensure that no adaptations occurred when performing the inspiratory muscle training protocol.

All subjects were required to maintain a training journal, in which they entered the date and time they participated in the inspiratory training during the training period, as well as any other physical activity they were currently participating in (running, biking, weight training, etc.). This training journal was designed to ensure that each subject properly followed the training protocol that was given to them, as well as informed the researcher of their physical activity routines.

Swim Training

Swim training was the same for both the control and experimental group. Each group was under the instruction of the same coach. This swim coach maintained the same program for all swimmers, which was recorded in each research participant’s training journals.

Posttraining, Day 1, Performance Measurements

All subjects participated in their second 200-yard swim trial in order to assess swimming performance changes following the period of inspiratory muscle training. Each swimmer was again verbally coached during their swim. The swim trials took place at Clovis North High School in Clovis, California and the Fig Garden Pool in Fresno, California.
Posttraining, Day 2, Lab Measurements

All participants again performed all measured respiratory function measurements from a standing position. Participants were again required to refrain from drinking caffeinated beverages 2 hours prior to testing, in which everyone reported compliance. FVC, FEV$_{1.0}$, FEV$_{1.0}$/FVC, and MVV$_{15}$ were all assessed three times. The average of the efforts were calculated, recorded, and then compared to baseline measures taken during the pretest assessment.

MIP measurements were assessed at posttest for each subject. The protocol remained the same as during the pretraining testing, in that the subject was required to exhale to residual volume, and then inhale maximally. Each subject performed three maximal inhalations with 20 seconds rest in-between each bout to prevent hyperventilation. Each maximal inspiratory pressure test was maintained for 1 second. The average of the efforts was recorded as the subject’s maximal inspiratory pressure.

Data Analysis

In order to determine if there were differences between groups, or differences between pretest and posttest scores, a two-way MANOVA with repeated measures across time (comparison of pre- and posttest scores) was conducted. To determine if there were differences between the groups with regard to change in performance from pretest to posttest, gain scores were calculated for all dependent variables by subtracting the posttest measures from the pretest measures. A series of one-way ANOVAs (one for each dependent variable) comparing the two groups were conducted. Significance was accepted at $p, \leq 0.05$ and all data were reported as means $\pm$ SD.
RESULTS

Program Adherence

Subjects within both the experimental group and the placebo group were similar. The experimental group had an average age of $48.5 \pm 10.21$ years, with six females and two males within the group. The placebo group had an average age of $38.2 \pm 5.27$, with five females and one male. All subjects from both groups have been swimming on a weekly basis under structured programs for at least 1 year. All other subjects within both groups complied with the protocol’s training schedule. On average, subjects took part in some form of structured physical activity $5.19 \pm 1.17$ days a week, and swam $2.24 \pm 0.74$ days per week. Throughout the entire 6-week protocol, three subjects in the placebo group forgot to undergo the inspiratory training 2 nonconcurrent days. In the experimental group, one subject forgot to perform the inspiratory training 2 nonconcurrent days, and one other subject forgot to perform the inspiratory training 1 day.

Effect of 6-Week Inspiratory Muscle Training

Following the 6-week training program for the inspiratory muscles, the gains score mean in the experimental group showed no significant difference from the gains score mean in the placebo group in any of the performance measurements. The gains score mean in the experimental group regarding the 200-yard swimming performance test was $-3.8771 \pm 2.6$ seconds. The gains score mean in the placebo group for the 200-yard swim was $-3.2483 \pm 2.4$ seconds.
There was no statistically significant difference between the two groups for this variable (p=0.66).

Following 6 weeks of inspiratory muscle training, the gains score mean in the experimental group for the forced expiratory volume in 1 second (FEV\textsubscript{1.0}) was 0.0888 ± 0.56 liters. The gains score mean in the placebo group for FEV\textsubscript{1.0} was 0.1360 ± 0.43 liters. Statistical significance was not found when comparing this variable between these two groups (p=0.88).

Following 6 weeks of inspiratory muscle training, the gains score mean in the experimental group for forced vital capacity (FVC) was -0.0575 ± 0.28 liters. The gains score mean in the placebo group for FVC was 0.1950 ± 0.41 liters. There was no statistical significance found when comparing the two gains score values from each group (p=0.19).

Following 6 weeks of inspiratory muscle training, the gains score mean for the experimental group for the ratio of FVC/FEV\textsubscript{1.0} was 3.6763 ± 13.97 liters. The gains score mean in the placebo group for this same variable was 6.4550 ± 12.49 liters. There was no statistical significance when comparing this variable between the two groups (p = 0.71).

Following 6 weeks of inspiratory muscle training, the gains score mean in the experimental group for maximal voluntary ventilation (MVV\textsubscript{15}) was 3.4325 ± 19.03. The gains score mean in the placebo group was 22.1883 ± 32.52. Although there appeared to be a very large difference in the gain score mean of the placebo group versus the gain score mean of the experimental group, there was no statistical significance found when comparing the two groups (p = 0.19).

Following 6 weeks of inspiratory muscle training, the gains score mean in the experimental group for maximal inspiratory pressure was -1.3337 ± 10.94 cm
H₂O. The gains score mean in the placebo group was 4.5333 ± 16.66 cm H₂O.

Statistical significance was not found when comparing the two groups (p = 0.44).

All mean gains scores are listed in Table 1. No statistical significance was found in any variable when the two groups were compared. Values are means ± the standard deviation.

Table 1
Comparison of the Mean Performance Gain Scores

<table>
<thead>
<tr>
<th>Gain Score Measurements</th>
<th>Experimental Group</th>
<th>Placebo Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain Score, 200-yard Swim</td>
<td>-3.8771 ± 2.59</td>
<td>-3.2483 ± 2.38</td>
</tr>
<tr>
<td>Gain Score, FEV1.0</td>
<td>0.0888 ± 0.56</td>
<td>0.1360 ± 0.43</td>
</tr>
<tr>
<td>Gain Score, FVC</td>
<td>-0.0575 ± 0.28</td>
<td>0.1950 ± 0.41</td>
</tr>
<tr>
<td>Gain Score, FEV1.0/FVC</td>
<td>3.6763 ± 13.97</td>
<td>6.4550 ± 12.49</td>
</tr>
<tr>
<td>Gain Score, MVV</td>
<td>3.4325 ± 19.03</td>
<td>22.1883 ± 32.52</td>
</tr>
<tr>
<td>Gain Score, MIP</td>
<td>-1.3337 ± 10.94</td>
<td>4.5333 ± 16.66</td>
</tr>
</tbody>
</table>
Chapter 5

DISCUSSION

The purpose of the present study was to determine whether 6 weeks of regular inspiratory muscle training would exhibit improvements in maximal inspiratory pressure, various respiratory measures, and 200-yard swimming performance times within master-level swimmers. The following results demonstrate that 6 weeks of inspiratory muscle training does not have an ergogenic effect on swimming performance in this specific population. It also does not appear to have a positive effect on maximal inspiratory pressure measurements in this specific population, either. However, it should be noted that there was considerable variance within the data, and that a more definitive answer to the research questions may require further studies with a more homogeneous subject pool. This present study’s population differed greatly in swim experience and skill as well as in age. Future research could be done with a more narrow range of swimming experience (e.g., 6 months to 1 year swimming experience) required by the subject in order control for skill development or lack of skill development contributing to the performance scores. Future research could also limit the age range of master level swimmers (18-25 years of age) in order to limit potential variance caused by aging of the subject.

These results are consistent with Sonetti et al. (2001), who found no difference in MIP measurements or performance measurements following 5 weeks of inspiratory muscle training using the same POWERbreathe® training device on a population of competitive cyclists. This study investigated the effects of inspiratory muscle training on the time trial performance times for nine
competitive cyclists. This present study followed a protocol for 1 week longer than Sonetti et al., yet there was no significant difference in the MIP and performance values. Although the results of this present study are consistent with the findings of Sonetti et al., the failure for change in the measured values may simply be due to the short length of the inspiratory training program (5-6 weeks).

This present study’s results were also consistent with the findings of Mickleborough et al. (2008) who investigated the effects of inspiratory muscle training on a population of competitive swimmers. They suggested that some athletic groups, specifically swimmers, may lack the ability to benefit from inspiratory muscle training. This thought was instigated following the results of the study, which stated that inspiratory muscle training in addition to a swim training program did not result in additional pulmonary or respiratory muscle adaptations beyond swim training alone (Mickleborough et al., 2008). This present study supports previous findings that swim training increases static and dynamic lung volumes. Following consistent swim training, swimmers have been found to experience an increase in inspiratory force production near total lung volume, due to the increase of large tidal volumes being achieved during swim training (Mickleborough et al., 2008). This, in turn, may result in conditioning of the accessory neck and chest wall muscles, which inspiratory muscle training is designed to do. If these above findings are accurate, then swimmers who participate in strenuous swim training on a regular basis would already be conditioning their accessory breathing muscles simply by undergoing swim training, thus causing inspiratory muscle training to be ineffective in this specific population. The results reported by Mickleborough et al. are consistent with findings from this present study, in that no real changes were seen between the swimmers who underwent inspiratory muscle training and those who underwent
placebo training, since all had been conditioning their inspiratory muscles simply by undergoing regular swim training.

The results from this study do conflict with multiple studies that did see increases in both MIP measurements and performance measurements following structured inspiratory training (Griffiths et al., 2007; Johnson et al., 2007; Tong et al., 2008). Yet all these studies investigated various athletic populations, from soccer players to rowers. This difference in population groups could have influenced the results of the studies, thus potentially giving explanation to the conflicting results of this particular investigation. Our specific population also consisted of swimmers with a mean age of 44 years old. This is in contrast to the mean ages of other subjects in various studies, such as Boutellier et al. (1992), whose mean age of subjects was 23 years old. This also conflicts with Tong et al.’s study, whose mean age in the control group was 22 years of age and the mean age in the trained and placebo group was 21 years of age. This is a significant age difference. It has been suggested that skeletal muscular force production decreases with aging and fatigability of skeletal muscle increases with aging (Spirduso, 1995). This decrease in strength and increase in fatigue of aged muscle may explain the difference of results found within this present study and those previously mentioned studies that saw positive changes in performance measurements following inspiratory muscle training. To date, no study has investigated the effects of age on inspiratory muscle adaptation to training, so further investigation is warranted to explore the above option as a limiting factor in the use of this controversial form of training.

Although many studies suggest that inspiratory muscle training may lead to improvements in various spirometry measurements and athletic performance, the results of this study are in direct contrast to these suggestions. Due to the
conflicting nature of populations and training protocols used when investigating this particular phenomenon, more studies will be necessary before coming to a definitive conclusion on the ability of this device to enhance performance.
REFERENCES


APPENDICES
APPENDIX A
INFORMED CONSENT
Informed Consent

Title of Project: The effects of an inspiratory muscle training program on maximal inspiratory pressure and swimming performance

Principal Investigator: Amanda Stetler (Graduate Student, Department of Kinesiology)

Co-Investigator: Felicia Greer, Ph. D. (Associate Professor, Department of Kinesiology)

The purpose of this study is to determine the effects of a 6 week inspiratory muscle training program on measurements of inspiratory muscular strength and on 200 yard swim performance times. Respiratory function measurements will also be assessed before and after the training period.

If you decide to participate in this study, we will require your attendance at the Human Performance Laboratory (HPL), located in the South Gym room 139 on 2 separate occasions and at the Clovis North or Fig Garden Swimming Pool at 2 different times. The first day in each environment will involve an introduction to the experimental procedure.

Pre-Post Testing, Day 1: Laboratory Measurements

For the laboratory testing sessions, you will report to the HPL where you will be asked to perform various respiratory function tests. You will be asked two
hours prior to laboratory testing, to refrain from the intake of caffeinated food or beverages. Respiratory measurements will all be taken using a spirometer, and will be performed from a seated, upright position. These measurements include vital capacity, forced vital capacity, forced expiratory volume in one second, and forced inspiratory volume in one second. Maximal Inspiratory Pressure will also be assessed to determine baseline inspiratory muscle strength. You will be given two practice trials to familiarize yourself with the testing protocol. You will then be asked to exhale completely, and then inhale with maximal effort for one second. This will be repeated 5 times, with a 20 second rest between each trial. During each test you will be asked to perform with a maximal effort.

Pre-Post Testing, Day 2: Field/Performance Measurements

For the testing session at the pool, you will be required to perform one 200 yard swim as fast as possible. Prior to performing the swim, you will undergo a standardized warm-up. During the 200 yard swim you will be asked to perform a maximal effort.

6-Week Inspiratory Muscle Training Program

You will be given a POWERbreathe® inspiratory muscle trainer to use during the 6-week training period. You will be instructed by the researcher how to use the device correctly. The training protocol is as follows:
30 maximal inspirations, with 10 seconds of rest between each inspiration

This activity will be performed once daily, 6 days a week for the 6 week training period.

The resistance of the device will only be adjusted by the researcher. You will be instructed to not change the resistance load of the device at anytime during the training period. You will be asked to maintain a training journal of the date, time, etc. of your inspiratory program during the 6 weeks of the training.

Any information that is obtained through this study will be strictly confidential and will only be disclosed with your permission or as required by law. If you give us permission by signing below, results from this study will be made available to the public through submission to scientific journals and presentation at professional conferences, however, you will remain anonymous. It is the intent that publication/presentation of the results will add to the body of knowledge in the related fields of exercise science and physiology. You may request a copy of the results of this investigation at any time.

Your choice to participate in this research study will in no way affect your association with Fresno State University. If you chose to participate, you are free to, at any time, discontinue your participation and will not be subject to any penalty for your withdrawal. The committee on the Protection of Human Subjects at CSU, Fresno has reviewed and approved the procedures for the present study.
If you have any questions/comments regarding your involvement in this study, please feel free to contact Amanda Stetler, Dr. Felicia Greer or the Chair of the University Institutional Review Board, Dr. Constance Jones.

You are making a decision whether or not to participate in this study, your signature indicates that you have decided to participate in this study having read the information above.

____________________________________________________
Participant’s Signature      Date

____________________________________________________
Investigator’s Signature      Date
APPENDIX B
HEALTH HISTORY QUESTIONNAIRE
Health Status Questionnaire

This questionnaire identifies adults for whom physical activity might be inappropriate, specifically physical activity that may be inappropriate for participation in this particular research study.

Section 1: Personal and Emergency Contact Information

Name: ___________________________ Date of Birth: _________
Address: _________________________ Phone: __________

Physician’s Name: __________________________
Height: _________ Weight: _________

Person to contact in case of emergency
Name: ___________________________ Phone: __________

Section 2: General Medical History

Please check the following conditions you have experienced.

Heart History

☐ Heart attack
☐ Heart surgery
☐ Cardiac catheterization
☐ Coronary angioplasty (PTCA)
☐ Cardiac Pacemaker
☐ Cardiac rhythm disturbance
☐ Heart Valve Disease
☐ Heart Failure
☐ Heart Transplantation
☐ Congenital Heart Disease

Symptoms

☐ You experience chest discomfort with exertion
☐ You experience unreasonable shortness of breath at any time.
☐ You experience dizziness, fainting, or blackouts
☐ You take heart medications.
**Additional Health Issues**

- You have diabetes (type 1 or type 2)
- You have asthma
- You have a specific lung disease (e.g. emphysema)
- You have burning or cramping sensations in your lower legs with minimal physical activity
- You have joint problems (e.g. arthritis) that limits your physical activity
- You have concerns about the safety of exercise
- You take prescription medications
- You are pregnant.

**Section 3 Risk Factor Assessment**

**Risk Factors for Coronary Heart Disease**

- You are a man older than 45 yr.
- You are a woman older than 55 yr. have had a hysterectomy, or are postmenopausal
- You smoke or you quit smoking within the previous 6 mo.
- Your blood pressure is \( \geq 140/90 \) mmHg
- Your blood cholesterol is \( > 200 \text{mg/dl} \)
- You have a close male blood relative (father or brother) who had a heart attack or heart surgery before the age of 55 or a close female blood relative (mother or sister) who had a heart attack or heart surgery before the age of 65.
- You are physically inactive (you get <30 min of physical activity at least 3 days per wk).
- Your waist circumference is \( >40 \) in (101.6 cm in men or \( >35 \) in. (88.9 cm in women).

**Section 4: Medications**

Are you currently taking any medication

- Yes
- No

If yes, please list all of your prescribed medications and how often you take them whether daily (D) or as needed (PRN).

Of the medications you have listed, are there any you do not take as prescribed?
Section 5: Physical Activity Patterns and Objectives

List the type, frequency, intensity (e.g., low, moderate, strenuous), and duration of your weekly exercise.

________________________________________________________________________

________________________________________________________________________

List your specific goals for your exercise program. ________________________

________________________________________________________________________

Please inform the fitness professional immediately of any changes that occur in your health status.

Patient Information Release Form

If you have answered yes to questions indicating that you have significant cardiac pulmonary, metabolic, or orthopedic problems that may be exacerbated with exercise, you agree it is permissible for us to contact your physician regarding your health status.

Signature: ____________________________ Date: _________

Fitness Staff Signature: ________________ Date: _______________
APPENDIX C

6-WEEK INSPIRATORY TRAINING PROTOCOL
6-Week Inspiratory Training Protocol

30 maximal inhalations using the POWERbreathe® training device. Each inhalation should be maintained for a minimum of 1 second each. Every maximal inhalation should be separated by a 10 second rest period.

1. This training should occur 6 days a week, once daily.

2. Please maintain a daily training log, specifying when (day & time) you used the POWERbreathe® device, as well as other structured exercise you regularly participate in (e.g. ran 5 mi, swam 1500 yards, etc...)

3. The resistance load of the inspiratory device will be adjusted every two weeks by the researcher or with instructions given by the researcher. Participants should not adjust the load of the inspiratory device without specific instructions from the researcher or researcher’s assistant.

4. This training program should be maintained a total of 6 weeks.

5. Please notify the researcher immediately if you become sick with the cold or flu, and we will discontinue the training program.
California State University, Fresno

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Amanda Stetler
Type full name as it appears on submission

April 13, 2010
Date