ABSTRACT

EXAMINATION OF SPEECH AND RESPIRATORY PARAMETERS DURING MODERATE AND HIGH INTENSITY WORK

by Jenny Christine Hipp

Speaking while performing physical work tasks is known to decrease ventilation, which may in turn, impair speech fluency. The purpose of this study was to determine how speech fluency is affected during a simultaneous speech and work task performed at two work intensity levels. Twelve healthy participants performed steady-state work tasks at either 50% or 75% of VO$_2$ max (maximal O$_2$ uptake) for a total of six minutes after completing a rest-to-work transition period. Initially the participants did not speak, but when they returned for further testing, a similar task was completed with the addition of speaking. Results demonstrated significant differences in dyspnea ratings, number of words per phrase, and number of inappropriate pauses between the two intensity levels. The speaking condition influenced all variables except heart rate. The higher intensity task was more challenging for the participants and had the greatest impact on speech fluency.
EXAMINATION OF SPEECH AND RESPIRATORY PARAMETERS DURING MODERATE AND HIGH INTENSITY WORK

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Jenny Christine Hipp
Miami University
Oxford, OH
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Advisor__________________________________________
Susan Baker, Ph.D.

Reader____________________________________________
Helaine Alessio, Ph.D.

Reader____________________________________________
Kathleen Hutchinson, Ph.D.
**TABLE OF CONTENTS**

CHAPTER I: Introduction ............................................................................................................. 1

*Control of Involuntary Respiration* ....................................................................................... 1

*Voluntary Control of Respiration* ........................................................................................ 2

*Introduction to Respiration and Speaking* .......................................................................... 2

*Introduction to Respiration and Working* .......................................................................... 3

*Respiration, Speech, and Work* .......................................................................................... 4

*Populations at Risk* ............................................................................................................ 5

Statement of Problem ........................................................................................................... 6

Research Questions .............................................................................................................. 7

CHAPTER II: Review of the Literature ...................................................................................... 8

*Respiration* .......................................................................................................................... 8

*Quiet Breathing* .................................................................................................................. 8

*Speech Breathing* ............................................................................................................... 9

*Respiration and Sustained Voicing* .................................................................................... 10

*Respiration and Conversational Speech* ......................................................................... 12

*Phonation* ........................................................................................................................... 13

*Breathing During Physical Work* ....................................................................................... 15

*Simultaneous Speech and Work* ...................................................................................... 16

Statement of Purpose .......................................................................................................... 20

Research Hypotheses ........................................................................................................... 21

CHAPTER III: Methods ............................................................................................................ 22

*Participants* .......................................................................................................................... 22

*Procedure* ........................................................................................................................... 22

*Laryngeal Screening* ......................................................................................................... 22

*Pulmonary Screening* ....................................................................................................... 23

*VO₂ max Test* ..................................................................................................................... 24
Experimental Work Tasks.................................................................25
Non-Speech Tasks...........................................................................25
Simultaneous Speech and Work Tasks.........................................26
Statistical Analysis........................................................................27
CHAPTER IV: Results......................................................................29
  Descriptive Analysis.................................................................29
  Inter-rater Reliability...............................................................32
  Intra-rater Reliability...............................................................32
Inferential Analysis for Research Questions.................................33
CHAPTER V: Discussion................................................................36
  Background................................................................................36
  Review of Results by Research Question.................................37
  Limitations................................................................................41
  Future Research.........................................................................41
  Chapter Summary........................................................................45
REFERENCES..................................................................................46
Appendix A: Health Questionnaire...............................................50
Appendix B: The Rainbow Passage...............................................51
Appendix C: Additional Phonetically Balanced Reading Passages...52
LIST OF TABLES

Table 1. Physical Attributes of Participants…………………………………………... 22
Table 2. Pulmonary Measures………………………………………………………… 24
Table 3. VO₂ max Values…………………………………………………………... 25
Table 4. Heart Rate (beats per minute) during All Tasks……………………………... 29
Table 5. Borg Values for Ratings of Perceived Breathlessness during All Tasks……29
Table 6. Number of Words per Phrase during All Speaking Tasks………………..30
Table 7. Number of Inappropriate Pauses during All Speaking Tasks………………...30
Table 8. T-tests for an Average of Times 1 through 3 Values Compared to Baseline...34
LIST OF FIGURES

Figure 1. Relaxation Pressure Curve
Figure 2. Borg Scale
Figure 3. Average Heart Rate during All Tasks
Figure 4. Average Borg Scale Ratings during All Tasks
Figure 5. Average Words per Phrase
Figure 6. Average Number of Inappropriate Pauses
CHAPTER I
Introduction

Aerobics instructors, military personnel, emergency personnel, and vocal performers who perform choreography face the challenge of speaking (or singing) while working for extended periods. When performed simultaneously, speaking and physical work place a greater demand on the respiratory system than when the two tasks are performed independently.Pairing speech with work changes breathing patterns that alter the homeostasis of the respiratory system. At times, this limitation of the respiratory system may require some professionals to choose between speaking and continuing to perform aerobic work, which ultimately affects job performance and may have longer term consequences for speech quality.

Control of Involuntary Respiration

The primary purpose of respiration is the exchange of oxygen (O\textsubscript{2}) and carbon dioxide (CO\textsubscript{2}) in order to ensure maintenance of blood-gas homeostasis (Powers & Howley, 2004). Ventilation (respiration) is the mechanical process of moving air in and out of the lungs (Powers & Howley, 2004). The lungs themselves have very little muscle tissue, and thus the rib cage and torso muscles are responsible for inflating and deflating the lungs. Breathing is generally divided into two phases: inspiration and expiration. The chest cavity expands during inspiration because of muscle forces that aid in lifting the rib cage upward and outward (Hixon, 1973). During inhalation as the chest cavity expands and lifts the rib cage, it simultaneously works to expand and lift the lungs as well because the lungs are attached to the rib cage though pleura, creating the lungs-thoracic unit. As the lungs expand and the volume increases, the air pressure within the lungs falls below the pressure of the air outside the body. The drop in pressure creates a partial vacuum, which allows air from outside the body to enter the lungs (Titze, 1994).

Typically, little muscular effort is needed during resting tidal (quiet) breathing, as this type of breathing only requires inspirations of approximately 10% of vital capacity (VC; the amount of air that can be forcibly exhaled after a full inspiration; Hixon, 1973; Titze, 1994). During the expiratory phase, air flows out of the lungs due to the passive forces of the relaxing inspiratory muscles and of the elastic recoil of the lungs-thoracic unit. The
rib cage and the diaphragm return to their original positions, and the lungs deflate with them.

Quiet breathing is an automatic, involuntary response. It is also known as a metabolic response because peripheral and central chemoreceptors and branches of the Vagus nerve send sensory information about O2 levels to the respiratory control center located in the brainstem (Phillipson, McClean, Sullivan, & Zamel, 1978). The primary goals of the respiratory control center are to maintain homeostasis of O2 and CO2 and to perform normal metabolic tasks (West, 2000).

Voluntary Control of Respiration

Any deviations from the respiratory patterns needed for quiet breathing are generated by voluntary or behavioral controls. Examples of such deviations include breathing patterns required for speech and those required for physical work. The behavioral control system, which is located in the forebrain of the cortex, is responsible for overriding the metabolic control system (Bailey & Hoit, 2002). Phillipson et al. (1978) found that the metabolic control system relaxes during voluntary respiratory tasks without conscious effort, and the respiratory system is able to perform both respiratory and voluntary functions simultaneously.

Introduction to Respiration and Speaking

Changes in breathing patterns required for speech production are necessary to ensure appropriate linguistic phrasing. In order to initiate speaking, the individual must override the metabolic control system with voluntary behavioral controls (Phillipson et al., 1978). Breathing patterns noted during speaking are characterized by rapid inspirations and longer expiration times (Bailey & Hoit, 2002). This speech breathing pattern allows for minimal breaks in continuous speech and ensures phrase completion. When speaking at rest (not working), healthy individuals are able to tolerate the temporary imbalance of O2 and CO2 created by fewer inspirations.

In order to perform the altered breathing patterns observed during speech breathing, the respiratory muscles must change their role as well. To produce sound, the vocal folds need to vibrate, and a continual flow of air leaving the lungs is the principle driving force that sustains vocal fold vibration (Hixon, 1973). The air pressure required to initiate and sustain vocal fold vibration is called subglottal pressure, and values are
typically noted as 5 cmH\textsubscript{2}O for normal intensity and can be over 20 cmH\textsubscript{2}O for loud speech. Typically, during normal speech, individuals breathe in to about 60\% of VC to initiate voicing (Hixon, 1973). Thus, the difference between the percent of vital capacity needed for speech is significantly greater than the amount needed during tidal breathing (10\% VC), which signifies more active muscular effort needed from the inspiratory muscles.

Increased muscular effort from the muscles of inspiration during a speaking task is also noted in the form of inspiratory checking. In order to sustain a tone, carry on a conversation, or sing, it is necessary to control the rate of airflow as it exits the lungs. If all the air inspired were expired at once, then subglottal pressure requirements for normal voicing would be exceeded. The vocal folds would be blown apart to a greater degree, resulting in an increase in the intensity of the sound. Therefore, active muscle contraction from the muscles of inspiration act to counterbalance the passive forces of expiration, and the process is termed inspiratory checking (Hixon, 1973). By gradually relaxing the diaphragm and external intercostal muscles (located on the rib cage), the rate with which the lungs deflate, and the rate of airflow during expiration are both slowed, allowing speech to occur in a controlled manner.

Introduction to Respiration and Working

As previously mentioned, the voluntary task of physical work requires that higher cortical control centers alter, or override, metabolic breathing patterns. In order for a muscle to contract, O\textsubscript{2} is needed to produce adenosine triphosphate (ATP), which is the immediate source of energy for muscular contraction (Powers & Howley, 2004). In a state of continuous aerobic work, greater demands of O\textsubscript{2} are required, creating a state of high respiratory drive. During aerobic work, in order to ensure that the O\textsubscript{2} needs of the working muscles are met, both the amount of air inspired and the number of breaths taken per minute increase. The body’s capacity for transmitting O\textsubscript{2} through the blood to the working muscles during physical work is termed maximal oxygen uptake (VO\textsubscript{2} max).

During physical work, West (2000) states that minute ventilation (breathing frequency x tidal volume) increases to about 15 times the individual’s resting level. He additionally states that breathing into a higher percentage of vital capacity (70-85\% VC) is necessary when working. Therefore, due to the increased inspired air during physical
work needed to meet the O\textsubscript{2} demands of the working muscles of the body, greater active contraction of the muscles of inspiration is needed as compared to both tidal breathing and speaking.

*Respiration, Speech, and Work*

Quiet breathing patterns alter upon combining speech and physical work. Higher cortical control centers simultaneously generate sufficient subglottal pressure for voicing and supply the working muscles of the body with enough O\textsubscript{2} to produce ATP. Furthermore, the respiratory system chemoreceptors and centers in the brain (apneustic and pneumotaxic areas) are still responsible for monitoring the O\textsubscript{2} and CO\textsubscript{2} levels in the body (Powers & Howley, 2004). The higher respiratory control centers must ensure that speech can still be intelligible while working; even though the individual has increased the number of inspirations taken and is breathing in to higher lung volumes (75-80% VC for physical work is significantly greater than the 60% VC needed for speech) all in an effort to meet the greater O\textsubscript{2} demands of the working muscles. Thus, in regards to intensity and phrase completion, the higher control centers have the added responsibility for controlling the rate of airflow in an attempt to speak at a normal intensity as well as ensuring that enough words are spoken in an utterance to maintain fluency. Additionally, in order to meet the greater demands for O\textsubscript{2}, inspirations (i.e., pauses) may be needed at locations that are not linguistically or grammatically appropriate, further reducing intelligibility.

It is likely that as the work task increases in intensity, the demands placed on the respiratory control centers in the brain may become too taxing or fatiguing. Decreasing speech intelligibility or dyspnea ratings could possibly be valuable indicators of an overworked system. Dyspnea is the uncomfortable sensation of breathing that occurs when the demand for ventilation is greater than the ability of the respiratory system to respond (Salzman, 1997). Thus, as the physiological needs of proper gas exchange and energy production tax the respiratory system during work, the voluntary task of speaking fluently and intelligibly will likely become compromised (Meckel, Rotstein, & Inbar, 2002).

Only two studies have specifically examined the relationship of speaking during physical work. Doust and Patrick (1981) studied six healthy young men’s speech
production at various workloads (determined by participants’ heart rate) while running on a treadmill. While speaking at each work level, the participants exhibited a significant reduction in ventilation (about 55% lower than control ventilation), which equated to an overall decrease in O$_2$ uptake. In a second study, Meckel, Rotstein, and Inbar (2002) studied fourteen healthy, young men who were required to speak and run at intensities of 65, 75, and 85% VO$_2$ max. Similar to the Doust and Patrick (1981) study, Meckel et al., also found that ventilation decreased, which subsequently decreased mean O$_2$ uptake during speech production at each work rate. As O$_2$ levels decreased, blood lactate levels increased indicating that the participants were utilizing anaerobic energy production to supply the working muscles with the O$_2$ needed for ATP formation. An anaerobic energy source is less efficient for longer durations of physical work than the aerobic energy system. Therefore, it is assumed that as individuals continue to perform a simultaneous speech and work task by using anaerobic energy production, then they will likely fatigue sooner, which may result in an earlier termination of the task.

One limitation to both studies is the fact that neither one specifically examined actual speech utterances. The fact that the participants experienced a decrease in mean O$_2$ uptake during a simultaneous speech and work task is valuable, but the clinical implications of decreased O$_2$ have not been explored. Therefore, it is necessary to examine the participants’ utterances to predict any possible long-term ramifications (i.e., developing a voice disorder) seen from speaking while working.

**Populations at Risk**

The likely strain placed on the respiratory system and the decrease in O$_2$ consumption is a major concern for certain professionals who are required to speak while working. Populations at risk include professionals such as aerobic instructors, military personnel, emergency personnel, and vocal performers who perform choreography. It would be helpful for both short- and long-term reasons to determine certain work intensities at which the decrease in O$_2$ uptake is significant enough to affect speech fluency and intelligibility so that the professionals can choose to either discontinue talking or decrease work intensity until the O$_2$/CO$_2$ balance is restored.

Previous literature involving the aforementioned population has primarily focused on the prevalence of voice disorders. Vocal nodules or hoarseness were the types of
voice disorders most often cited among populations of aerobic instructors (Heidel & Torgerson, 1993; Long, Williford, Olson, & Wolfe, 1997; Wolfe, Long, Youngblood, Williford, & Olson, 2001). Limitations in these studies were possible explanations as to why the prevalence of voice problems was significantly high (44% to 55%) in the aerobic instructors compared to the participants who were working only (i.e., following the aerobic instructor’s lead; Heidel & Torgerson, 1993; Long et al., 1997). One possible explanation is that the vocal folds are sometimes active in controlling laryngeal respiratory airflow. Thus, during high respiratory drive, it is possible that the vocal folds will assist in slowing down the rate of expiratory airflow during physical work so that speech can occur (Bartlett, Remmers, and Gautier, 1973). Although assistance from the larynx may be a possible explanation as to why aerobics instructors have a high percentage of voice problems, this potential compensatory strategy was not determined through this study design. Rather, this study sought to better understand the variations in speech characteristics while participants performed a simultaneous speech and work task.

**Statement of the Problem**

Little empirical evidence is available that examines the characteristics of speech utterances during physical work tasks. It is known that professionals required to speak while working have a higher incidence of voice disorders, but evidence is lacking in terms of understanding the demands placed on the respiratory system during simultaneous action of these two tasks. It is assumed that the two competing voluntary respiratory tasks can only override the metabolic control system for a fixed period. The O₂ demands of the body may eventually require the respiratory system to make a decision about which task can continue. If no choice is made, it is likely that speech fluency and intelligibility will be affected, which may ultimately impact job performance among professionals in this specific population. For example, if a singer is unable to complete the required choreography with simultaneous singing, he or she may not be cast for a desired role. Therefore, it is necessary to examine how specific work intensities affect speech characteristics that influence intelligibility and fluency, such as the number of words per phrase and appropriate placement of pause (i.e., inappropriate linguistic locations).
Research Questions

1. Do heart rate and dyspnea ratings during a simultaneous speech and work task differ significantly compared to a non-speech work task of similar intensity?

2. Do heart rate, dyspnea ratings, and speech parameters differ significantly from baseline during a simultaneous speech and work task at 50% of VO$_2$ max compared to the same task at 75% of VO$_2$ max?

3. Do heart rate, dyspnea ratings, and speech parameters differ significantly between a simultaneous speech and work task performed at 50% of VO$_2$ max compared to the same task at 75% of VO$_2$ max?

4. Does an individual’s VO$_2$ max influence sensation of dyspnea, words per phrase, and use of inappropriate pauses when measured after six minutes of physical work?
CHAPTER II
Review of the Literature

In order to understand the potential compensations and alterations that occur due to the required patterns of breathing for speech production during a simultaneous speech and work task, it is necessary to discuss the mechanics of the speech and respiratory systems. In this chapter, the function of the respiratory system at rest will be discussed. An explanation of the required breathing patterns for speech will follow, which will include a discussion of breathing patterns for sustained voicing and conversational speech. Then the breathing patterns required for speech production will be discussed in relationship to the increased O\textsubscript{2} needs during physical work. This section will also contain information about laryngeal anatomy and physiology.

Respiration

Respiratory forces provide the basic energy source for all speech and voice production (Hixon, 1973). The structure of the respiratory apparatus is housed in the torso, and it includes the thorax and the abdomen (Hixon, 1973). Within the thorax, protected by the rib cage, lie the lungs nearly filling the entire thoracic cavity. Each lung is light and flexible, which cause the lungs to have an inherent quality to collapse. With the lungs and thorax held together as a unit by pleural linkage, the respiratory apparatus assumes a natural resting position called resting expiratory level or function residual capacity (FRC) at which the force of the lungs to collapse is opposed by an equal and opposite force of the thorax to expand (Hixon, 1973). Furthermore, visceral and parietal pleura serve to minimize friction of respiratory movements and enable the lungs to expand and contract as the rib cage changes volume (Hixon, 1973; Zemlin, 1988).

Quiet breathing

Before discussing the relationship of respiration to speech, it is necessary to understand the physical process of quiet or tidal breathing. The respiratory system is the power source for speech as it creates the necessary pressure to initiate vocal fold vibration. In order to obtain the needed energy source for vocal fold vibration, the alveolar pressure must be lowered, which will generate the inward driving force to assist in filling the lungs with air. To create this change in pressure, active muscle contraction is needed to expand the entire thoracic cavity (Borden & Harris, 1980). The most
important muscle of inspiration is the diaphragm, which is a thin, dome-shaped sheet of muscle that is inserted into the lower ribs (Zemlin, 1988). Phrenic nerves from the cervical segments 3, 4, and 5 innervate the diaphragm (Kahane, 1986; West, 2000). Upon contraction, the abdominal contents are forced downward and forward, and the vertical dimension of the chest cavity is increased (West, 2000). In addition, the rib cage is lifted and moved outward by contraction of the external intercostal muscles, causing an increase in the transverse diameter of the thorax (Hixon, 1973; West, 2000). Intercostal nerves that exit the spinal cord at the same level as the phrenic nerves innervate the intercostal muscles (Kahane, 1986).

The active force of the inspiratory muscles causes the thorax to expand beyond its neutral resting position, which, in turn, results in a collapsing force during the expiratory phase. The collapsing force, often termed elastic recoil, is one of the passive forces observed during expiration that assists in deflating the lungs. Gravity also passively assists in expelling air from the lungs (Borden & Harris, 1980; Zemlin, 1988).

The processes involved in the cycle of quiet breathing are characterized as active inhalation and passive exhalation. The typical volume of air inhaled and exhaled in one breath is called the tidal volume. The average tidal volume for an adult human is around 500 mL of air, with an exchange of 6 to 9 liters of air per minute (Zemlin, 1988). During quiet breathing, the length of the inspiratory phase is approximately equal to the expiratory phase, and maintenance of the O₂/CO₂ homeostasis during quiet breathing is controlled by the metabolic response system located in the brainstem (Meckel et al., 2002; Phillipson et al., 1978). Yet, as previously discussed, breathing patterns alter according to the demands of voluntary tasks, such as noted in speaking and/or work.

Speech Breathing

Respiratory forces are the energy source behind all speech and voice productions and are required to regulate parameters such as intensity, vocal fundamental frequency, linguistic stress (emphasis), and the division of speech into various units (syllables, words, phrases; Hixon, 1973). Air must exit the lungs for voicing to occur. Relaxation pressure, caused by relaxing the muscles of inspiration, gravity, and elastic recoil forces of the lung-thoracic unit are the passive forces of expiration (Titze, 1994). If a large enough volume of air is inspired, the passive forces of expiration will suffice in
generating sufficient subglottal pressure. Subglottal pressure is the pressure generated directly below the vocal folds in order to initiate vocal fold vibration, and it is a percentage of alveolar pressure (Titze, 1994). Therefore, when speaking at rest at a comfortable intensity level, the only noted muscle activity is observed during inhalation. The dynamics of subglottal air pressure and vocal fold vibration will be discussed in the next section of text.

It is important to emphasize that the muscles of inspiration are contracting more during speech than during quiet breathing. The reason the inspiratory muscles are functioning at a higher effort level during a speaking task is due to the fact that speech increases ventilation patterns. Breathing patterns during speech are characterized by the increase of more rapid and shorter inspirations followed by longer expirations (Phillipson et al., 1978). This task involves active recruitment of higher cortical areas that take precedence over the metabolic control system, and as long as the speech task is not too demanding of the entire system, the speaker is able to continue speaking even at the cost of a slight imbalance in the O$_2$/CO$_2$ homeostasis (Phillipson et al., 1978). Speaking tasks do vary, though, and thus the relationship between the respiratory demands for sustained voicing and for connected speech will be discussed separately.

**Respiration and Sustained Voicing.** Sustained voicing is of significance for singers who often have to maintain a note at a constant intensity. Therefore, during sustained voicing, the respiratory pump’s task is to keep the airflow and lung pressure constant in order to achieve the required amount of subglottal pressure (Zemlin, 1988). Control of lung volume and respiratory muscle activity are vital actions needed to regulate subglottal pressure (Hixon, 1973). A better understanding of how voicing occurs is achieved by examination of the relaxation pressure curve (Figure 1). The relaxation pressure curve depicts the lung pressure generated at various lung volumes. In order to sustain a tone at a normal, conversational intensity, a lung pressure or subglottal pressure of 5 to 10 cmH$_2$O is needed (Hixon, 1973; Zemlin, 1988). From the curve, it can be seen that these pressures are produced at lung volumes between 35-55% of total lung capacity (TLC; Davenport & Sapienza, 2004). On the other hand, a greater amount of air is
Figure 1

Relaxation Pressure Curve

needed for louder speech, as it is necessary to breathe into 55-60\% of TLC in order to generate the higher value of subglottal pressure (15 to 20 cmH\textsubscript{2}O; Davenport & Sapienza, 2004; Zemlin, 1988).

When an individual breathes into a higher lung volume, active recruitment of the inspiratory muscles is needed to ensure that an appropriate subglottal pressure will be maintained. For example, if the individual takes a deep breath (80\% of VC), there may actually be an excess of subglottal pressure generated from high elastic recoil forces. This excess pressure may be controlled by keeping the diaphragm in a state of contraction into the expiratory phase (inspiratory checking; Leanderson & Sundberg, 1988).

Additionally, from the relaxation pressure curve, at very low lung volumes (20\% of VC), there is inadequate subglottal pressure (4-5 cmH\textsubscript{2}O) for speech production at a normal, conversational intensity (Davenport & Sapienza, 2004). An example of an instance where voicing is needed at low lung volumes is often observed when a singer desires to extend out a note during the most difficult part of the song without stopping to inhale. Thus, to continue singing, recruitment of the abdominal muscles, such as the external and internal obliques, the transversus abdominis, and the rectus abdominis, work to push inward on the abdominal contents. Compression of the abdominal contents pushes up on the diaphragm, further reducing the volume of the lungs, which ultimately aids in continuation of air flowing from the lungs (Titze, 1994; Zemlin, 1988). Speech production at these low lung volumes likely creates a temporary respiratory imbalance. The metabolic control system demands the body to inspire due to the reserves of O\textsubscript{2} being depleted. Yet, the voluntary control system in the cortex takes precedence in order to continue sustaining the note even at the cost of a temporary imbalance in O\textsubscript{2} and CO\textsubscript{2}.

Respiration and Conversational Speech. Respiratory demands for conversational speech are similar to the demands needed for sustained voicing. The expiratory phase is still longer than the inspiratory phase, and the observed lung volume used is also 35\% to 60\% of vital capacity (Borden & Harris, 1980; Zemlin, 1988). In addition, both tasks require an average subglottal pressure between 5 and 10 cmH\textsubscript{2}O (Hixon, 1973; Zemlin, 1988). Finally, in order to produce conversational speech with correct stress, intonation, and accurate termination of phrases for proper conversational flow, the behavioral control system overrides the metabolic control system. During conversational speech, a
temporary imbalance of O$_2$/CO$_2$ occurs because shorter and fewer inspirations are taken, which are followed by longer expirations (Bailey & Hoit, 2002). Yet, as with sustained voicing, as long as the two tasks do not place a significant amount of strain on the respiratory system, then the body is still capable of functioning in spite of the imbalance (Phillipson et al., 1978). Whenever an imbalance does become too great, though, the respiratory control center in the brainstem activates and initiates an inspiration (Phillipson et al., 1978). Typically, these shorter inspirations occur at appropriate phrase markers, such as the end of a sentence, and, in turn, fluency and intelligibility remain unaffected.

**Phonation.** Adequate breath support is vital in initiating vocal fold vibration (phonation) during speech production. The relationship between respiration and the vocal folds is very intricate, and any deficiencies observed in the respiratory system will adversely affect the overall functioning of the laryngeal mechanism (Stemple, Glaze, & Klaben, 2000). For phonation to occur, energy in the form of a relatively steady state or unobstructed stream of air from the lungs, must pass into the trachea and finally into the larynx (Zemlin, 1988). Within the larynx lies the vocal folds, which, upon beginning to vibrate, are responsible for generating the sound source called phonation and is the speech signal (Stemple et al., 2000).

The larynx is located in the midline of the neck, above the first cartilage of the trachea. The larynx typically represents the separation of the upper and lower vocal tract (Stemple et al., 2000). The hyoid bone and six cartilages form the structural framework of the larynx, which include the epiglottis, thyroid cartilage, cricoid cartilage, arytenoids, corniculate cartilages, and cuneiform cartilages (Stemple et al., 2000). The vocal folds themselves are comprised of four layers of tissue that surround the vocalis muscle (Zemlin, 1988).

The intrinsic muscles of the larynx have both attachments within the laryngeal cartilages, while the extrinsic muscles have one attachment within the larynx and the other attachment is on an external point (i.e., sternum or hyoid bone). Contraction of the extrinsic muscles serves to influence the height or the tension of the larynx as a gross unit (Kahane, 1986; Stemple et al., 2000). The intrinsic laryngeal muscles, which include the thyroarytenoid, posterior cricoarytenoid, lateral cricoarytenoid, interarytenoids (oblique
and transverse), and cricothyroid muscles, (1) abduct and adduct the vocal folds; (2) change the position of the laryngeal cartilages relative to each other; (3) change the dimensions and physical properties of the vocal folds (i.e., length, tension, mass/unit area, compliance, and elasticity); and (4) change the size of the space between the vocal folds (Kahane, 1986; Zemlin, 1988). Both the superior laryngeal branches and the recurrent laryngeal branches of the Vagus nerve (Xth cranial nerve) innervate the intrinsic muscles of the larynx (Hirano, 1981).

The complex process of vocal fold vibration is the product of aerodynamic and myoelastic forces. Van den Berg (1958) is credited with this classic explanation of vocal fold vibration, which recognizes the reciprocal role of the aerodynamic properties, subglottal pressure, and transglottal flow as they interact with elasticity of the vocal fold tissues (Kahane, 1986; Stemple et al., 2000). After inhalation, at the onset of phonation, intrinsic laryngeal muscles including the lateral cricoarytenoid muscle and the transverse and oblique interarytenoid muscles contract to adduct the vocal folds. By placing the vocal folds at the midline, an obstruction is created in the airway, which alters the flow of the outgoing air. Medial compression of the vocal folds generates a buildup of subglottal pressure beneath the vocal folds. When a sufficient amount of subglottal pressure exists, the vocal folds begin to be blown apart slightly, beginning at the lower edges and progressing superiorly (Van den Berg, 1958). A wavelike motion ensues as the upper portions continue to be directed away from midline by regeneration of the subglottal air pressure, while the lower edges that were displaced earlier begin to return toward midline (Kahane, 1986; Stemple et al., 2000).

The vocal folds return to the midline position because of elastic recoil and the aerodynamic process of the Bernoulli Principle. The Bernoulli Principle states that as an increased flow of air passes through a small opening between two structures, a momentary drop in pressure occurs along the medial margins of the vocal folds (Stemple et al., 2000; Zemlin, 1988). As a result of the decrease in pressure the vocal folds are drawn towards the midline. The vocal folds will continue to oscillate from the aerodynamic forces of pressure and flow until the air supply runs out or until the speaker chooses to terminate voicing. In either instance, the speaker will need to contract the posterior cricoarytenoid muscle in order to abduct the vocal folds so that inspiration can
occur. To reiterate, voicing at a comfortable intensity and pitch requires that the voluntary respiratory control system precede the onset of phonation. As stated earlier, the muscles of respiration perform the act of inspiratory checking so that the rate of airflow is exhaled at a controlled rate to ensure proper voicing.

Phonation also requires laryngeal action for the production of prosodic features of speech, such as stress and intonation used to signal questions, statements, and commands (Kahane, 1986; Stemple et al., 2000). Changes in these prosodic features are dependent upon variations in fundamental frequency and intensity, which changes by lengthening or shortening the vocal folds (Hirano, 1981). Although the role of the larynx influences these linguistic features of speech, the articulators (i.e., tongue, lips, teeth, mandible, and velopharyngeal mechanism) and resonating chambers (i.e., oral, nasal, and pharyngeal cavities) more greatly influence the refinement and characteristic differences of the various speech sounds (Titze, 1994).

**Breathing During Physical Work**

Until this point in the text, discussion has focused on normal breathing patterns as well as the changes in breathing patterns that occur during the voluntary task of speaking. Physical work is another important task that utilizes voluntary breathing patterns. The exchange of O$_2$ and CO$_2$ becomes more vital during physical work as the gas exchange demands increase enormously. Working muscles need O$_2$ to produce ATP in order to contract and continue to perform physical work. During work, deviations from tidal breathing conditions include instinctively increasing the percentage of vital capacity to 70-85% VC (as opposed to 10% VC for breathing at rest and 35-60% VC for speech) to ensure that appropriate O$_2$ and CO$_2$ levels are maintained (West, 2000). Therefore, a similar situation to speech breathing is created during work in that the behavioral control system overrides the metabolic control system.

The observed drive to increase ventilation during physical work is due to afferent input from neurons in working muscles that send projections to higher brain centers (Dempsey, Forster, & Ainsworth, 1994). Excited neurons cause an increase in the volume of air inspired and reflects the number of muscle motor units being recruited (Powers & Howley, 2004). Input to the respiratory control center may also come from chemoreceptors in the blood. The fact that the arterial partial pressure of carbon dioxide
(PCO$_2$) is tightly regulated during most types of submaximal work suggests that chemoreceptors and afferent neural feedback from working muscles act to fine-tune breathing to match the metabolic needs and thus maintain a constant arterial PCO$_2$ (Brice, Forster, Pan, Funahashi, Lowry, Murphy, et al., 1988; Wasserman, Whipp, & Casaburi, 1977). To summarize, the increase in ventilation during submaximal work is due to an interaction of both neural and chemical input to the respiratory control center.

**Simultaneous Speech and Work**

Aerobic instructors, military personnel, emergency personnel, and vocal performers who perform choreography are required to speak during physical work tasks. Both tasks performed simultaneously require a greater degree of effort from the muscles of respiration (as opposed to the effort needed for quiet breathing), and the two tasks are characterized by physiological deviations from quiet breathing patterns. Ultimately, the gas exchange homeostasis becomes temporarily out of balance due to the simultaneous action of the voluntary tasks of speaking and working. Even though it is known the imbalance occurs, the implications of combining speech with work have been researched on a limited basis.

There are only two reports of examinations of simultaneous speech and work. In one study, Doust and Patrick (1981) studied six healthy adult males during a steady-state treadmill work task at five different speeds. Participants performed seven minutes of work and read a passage for 30 seconds during the fifth minute of the task. At each work level, ventilation was reduced during speech by a mean of 55% of the control value, and respiratory frequency was reduced but tidal volume was not affected (Doust & Patrick, 1981). These findings illustrate that breathing patterns associated with speaking while doing physical work equate to fewer breaths taken per minute; however, the working muscles continue to demand O$_2$ for the production of ATP. It can then be assumed that the participants in the Doust and Patrick (1981) study could continue both tasks simultaneously as long as the intensity of the task remained at a level suitable for continued performance at decreased levels of O$_2$ uptake (VO$_2$). If the task continued longer than seven minutes, though, it is highly possible that fatigue associated with lack of sufficient O$_2$ uptake would halt the individual’s ability to maintain speech while
working. At that point, words per phrase should decrease and the number of inappropriate pauses should increase.

Meckel, Rotstein, and Inbar (2002) also examined the effects of speech production during a submaximal work task at various intensities in 14 healthy participants. On the first day of testing each participant’s VO₂ max was determined by an incremental maximal running test. The second day of testing required the participants to run at work intensities corresponding to 65%, 75%, and 85% of each participant’s VO₂ max. Each load lasted 6 minutes, and rest intervals were given in between each load. On the final day of testing, the exact protocol from day two was followed, except that for this test, the participants were required to speak. On each day of testing, several cardiopulmonary and metabolic responses to speech during work were recorded and analyzed. While speaking, mean O₂ uptake, minute ventilation, and breathing frequency all decreased significantly at each work rate with no significant change in tidal volume at any of the intensities compared to the non-speaking trials. Reduction in VO₂ for all work intensities ranged in descending order from 15% to 11% during mildest and hardest work rates, respectively. These findings further support the conclusions made by Doust and Patrick (1981) in that the working muscles continue to demand O₂, but the speech task controls the ventilation patterns creating a situation of decreased O₂ consumption as compared to the non-speech task.

Further findings by Meckel et al. (2002) may contribute to understanding alterations in speech characteristics while working. Both total respiration cycle time and expiration time increased by about 58% and 30%, respectively, across all work intensities. Speaking interferes with breathing patterns observed during the non-speaking task by the noted increase of the expiratory phase. During work alone, the body demands more O₂ in the form of larger inspirations. Yet, as indicated by the Meckel et al. study, the expiratory phase dominates and speech continues at the expense of the proper energy production. Speaking while working also inhibits the body from taking larger inspirations because, as stated previously, breathing in to greater percentages of VC (75-80% VC for physical work) is inefficient for voicing, and inspiring to larger volumes requires greater effort from the muscles of inspiration to perform inspiratory checking to control airflow during phonation.
Thus, in the competition between the ventilatory requirements for phonation and the physiological needs for efficient gas exchange and energy production during work, the voluntary respiratory control mechanisms must override the autonomic respiratory and gas exchange control systems (Meckel et al., 2002). As the simultaneous work with speaking task continues, greater demands are placed on both the respiratory control centers in the brainstem and in the forebrain of the cortex (Meckel et al., 2002). The act of maintaining speech while working results in a decrease in mean \( O_2 \) uptake, and since the expiratory phase dominated, an insufficient amount of \( O_2 \) is inspired during a work task. As \( O_2 \) is necessary for the production of ATP during aerobic energy production, a lack of sufficient \( O_2 \) would eventually require that anaerobic energy sources be utilized for muscular contraction (Meckel et al., 2002). The anaerobic (without oxygen) energy system relies on other compounds found in the body to fuel the working muscle. However, the supply of these compounds is not infinite.

During work, when ATP is needed for muscle contraction, the muscle cell utilizes the phosphocreatine pathway or it relies on the breakdown of glucose or glycogen (termed glycolysis; Powers & Howley, 2004). Muscle cells have limited supplies of phosphocreatine, which ultimately restricts the amount of ATP that can be produced via this anaerobic reaction (Powers & Howley, 2004). Reliance on glycolysis for muscular contraction is not a viable option either because if ATP is produced using glycolysis in the absence of \( O_2 \), then there is often an accompanying increase in lactic acid (Brooks, Fahey, & White, 2000). Anaerobic performance is best suited to shorter, more intense work bouts. Therefore, if \( O_2 \) uptake decreases during prolonged work tasks performed at low and moderate intensity levels due to the added task of speaking, then fatigue becomes a factor as the body attempts to produce ATP via the inefficient anaerobic energy system (Struder & Weiker, 2001). Fatigue is defined as a direct mismatch between the utilization rate of ATP by the muscle and the rate at which ATP is supplied (Powers & Howley, 2004). In conclusion, reliance on the anaerobic energy system could lead to faster fatigue times, which may result in shortening the speech and work task.

Monitoring blood lactate levels during a work task indicate when the body utilizes the anaerobic energy system (Powers & Howley, 2004). In the Meckel et al. study, a noted increase in blood lactate level from the non-speaking task to the simultaneous work
and speaking tasks was reported at each of the three work levels, possibly indicating that the participants had to utilize the anaerobic energy system to continue speaking while working. It is counterproductive for individuals to rely on a system primarily designed for shorter, higher intensity work bouts when trying to perform a work task of longer duration. Furthermore, in order to buffer the negative effects concomitant with lactic acid produced during a simultaneous speech and work task, the body will activate the respiratory control center to focus on increasing ventilation, which has the potential to disrupt the flow of speech.

Even though Meckel et al. did not specifically analyze altered speech characteristics, such as phrase length and pause placement, it can be concluded that after only six minutes of work at a constant intensity level, O$_2$ levels had decreased enough to eventually require more frequent inspirations that would interfere with proper phrasing during speech. Therefore, it can be assumed that at some point the individual will have to increase inspirations in order to continue performing the work task at the desired intensity, which is likely to interfere with appropriate phrasing for speech.

Alterations in speech characteristics are likely not the only adverse side effect of the increased strain placed on the respiratory system during simultaneous speech and work tasks. Increases in O$_2$ demand from the working muscles equate to a greater amount of blood pumped by the heart (Powers & Howley, 2004). Whenever the workload increases (i.e., speaking while working), the working muscles demand even more O$_2$, and as a result, heart rate increases in an attempt to get oxygenated blood to the working muscles. Consequently, as heart rate increases and O$_2$ uptake decreases, breathing becomes more uncomfortable, and this sensation is termed dyspnea. As long as the task is not too taxing on the heart and lungs, then the individual can continue performing the speech and work task using the aerobic (with oxygen) energy system. Yet, if the task elicits a strong sensation of breathlessness and a simultaneous increase in heart rate, then the individual approaches the anaerobic threshold and metabolic control centers will ultimately take precedence over the act of speaking.

By focusing on appropriate breathing patterns needed to sustain adequate O$_2$ uptake during the speech and work task, appropriate speech phrasing becomes secondary. As stated previously, an inability to perform speaking and work at the same time may
affect job performance for certain professionals. Therefore, of greater concern, is determining the point at which the O\(_2\)/CO\(_2\) imbalance becomes too great and the person must choose between speaking and work, or ceasing both. Understanding the demands placed on the respiratory system during simultaneous speech and work tasks will enable the professional to make any necessary compensations in speaking (i.e., say fewer words in the next couple of utterances) or during work (i.e., decrease the intensity level of the work task) so that the professional is able to complete job tasks.

Statement of Purpose

A study design that evaluates the variability in speech characteristics during simultaneous speech and work tasks will lead to a better understanding of how the body reacts to the situation created when the two respiratory acts (work versus speech) concurrently compete for control over the respiratory system. Knowing how the rival respiratory acts affect speech intelligibility will ultimately be of value for professionals that are required to perform the two tasks at the same time. Only two studies have attempted to examine the relationship between speech and work, however, those studies did not specifically compare changes in characteristics of speech during a speech and work task.

These studies did determine that mean O\(_2\) uptake decreased significantly during the various simultaneous speech and work tasks. The decrease in O\(_2\) uptake is indicative of the competition between the respiratory patterns required for speaking and working. It is expected that the decreased levels of O\(_2\) as well as the reliance on the anaerobic energy system will eventually be too taxing on the respiratory system, and eventually, the need to inspire more O\(_2\) will decrease the fluency of speech production (by decreasing the number of words per phrase and increasing the use of inappropriately placed pauses). Therefore, an evaluation of various physiological changes (heart rate and dyspnea) as well as of the changes seen in speech fluency while working will benefit the group of professionals required to speak and work simultaneously. The purpose of this present study is to compare simultaneous speaking and work tasks to non-speaking work tasks in terms of heart rate, dyspnea, and changes in specific speech parameters such as pause placement and number of inappropriate pauses used when speaking at rest as compared to speaking while working.
Research Hypotheses

It is hypothesized that:

1. heart rate and dyspnea ratings will significantly increase during a simultaneous speech and work task compared to a non-speech work task of similar intensity.

2. during the simultaneous speech and work task, heart rate, dyspnea ratings, and the number of inappropriate pauses will significantly increase from baseline, and the number of words per phrase will significantly decrease from baseline.

3. heart rate, dyspnea ratings, the number of inappropriate pauses, and the number of words per phrase will all significantly differ between a moderate (50% of VO\(_2\) max) and a high (75% of VO\(_2\) max) simultaneous speech and work.

4. individuals with a greater VO\(_2\) max will have a lower sensation of dyspnea, and use of inappropriate pauses with a greater amount of words per phrase at the end of the task compared to the baseline measures during the simultaneous speech and work task performed at a similar work load.
CHAPTER III

Methods

Participants

Twelve participants between 18 and 25 years of age (mean = 20.83 years; SD = 2.33) were recruited from the Oxford, Ohio, area. Half of the participants were male, and the other half of the participants were female. Only participants who currently performed at least 30 minutes of physical activity at a moderate intensity level at least 3 days per week were recruited. Participants had no current history of heart, lung, neurological, immune system disease, or voice disorder. Participants were excluded if they had smoked within the last 5 years or were currently taking medications for hypertension, such as Beta Blockers. Health history was determined by a health questionnaire (Appendix A). Participants were made aware of procedures and risks involved for performing the tasks, and all gave signed informed consent for participation. Table 1 displays the means and standard deviations for the age, height, and weight of each of the twelve participants.

Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>20.67</td>
<td>21.00</td>
<td>20.83</td>
</tr>
<tr>
<td>SD</td>
<td>2.73</td>
<td>2.10</td>
<td>2.33</td>
</tr>
<tr>
<td>Height (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>179.92</td>
<td>165.95</td>
<td>172.92</td>
</tr>
<tr>
<td>SD</td>
<td>7.08</td>
<td>3.47</td>
<td>9.02</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>85.49</td>
<td>56.67</td>
<td>71.08</td>
</tr>
<tr>
<td>SD</td>
<td>3.27</td>
<td>4.45</td>
<td>15.51</td>
</tr>
</tbody>
</table>

Procedure

Laryngeal Screening

Participants were examined for vocal fold health via laryngeal videostroboscopy. The laryngeal videostroboscopic examination was performed using a 70° rigid endoscope (Kay Elemetrics) to document the function of the vocal folds. The participant was instructed to open his/her mouth and produce a prolonged /i/ sound during the strobe procedure in order to obtain a clear view of the larynx, which was projected on a video
monitor. The videostroboscopy exam ruled out any pre-existing conditions to ensure that each participant had healthy, normally functioning vocal folds. The primary abnormalities that would have excluded a participant included a lesion on the vocal folds or evidence of laryngeal muscle weakness (as seen by a large posterior glottal chink). All participants screened had no signs of abnormal vocal fold health as determined after evaluating for a complete glottic closure pattern, proper amplitude of vibration of the true vocal folds, presence of the mucosal wave bilaterally, proper phase symmetry and closure, and lack of edema and erythema of the true vocal folds bilaterally. No participant presented with evidence of mass lesion, paralysis, or paresis.

*Pulmonary Screening*

Following the completion of the laryngeal exam, baseline pulmonary function testing was completed using a spirometer (Spirovision 3+, Future Med) to screen for any abnormal breathing status and to determine the integrity of the airways. Forced vital capacity (FVC) measures the volume change of the lungs between a full inspiration and a maximal exhalation. Forced expiratory volume in one second (FEV₁) is the volume exhaled during the first second of a forced expiratory maneuver after maximal inhalation. Both measures are frequently used to assess airway obstruction, bronchoconstriction, or bronchodilation (Powers & Howley, 2004). Maximal voluntary ventilation (MVV) was determined by encouraging the patient to breathe at their maximal tidal volume and their maximal respiratory rate for 12 seconds; the volume of air expired was expressed in L/min. The MVV is a more demanding task and it can be used to reveal the diminished reserves of weak respiratory muscles. All participants were within normal limits (see Table 2; American College of Sports Medicine, 2000).
Table 2

Pulmonary Measures

<table>
<thead>
<tr>
<th>Variable</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC (L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>5.28</td>
<td>3.59</td>
<td>4.44</td>
</tr>
<tr>
<td>SD</td>
<td>0.46</td>
<td>0.46</td>
<td>0.99</td>
</tr>
<tr>
<td>Mean % predicted</td>
<td>104.45</td>
<td>92.77</td>
<td>98.60</td>
</tr>
<tr>
<td>FEV1 (L/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>2.65</td>
<td>3.44</td>
</tr>
<tr>
<td>SD</td>
<td>0.57</td>
<td>0.73</td>
<td>1.04</td>
</tr>
<tr>
<td>Mean % predicted</td>
<td>98.05</td>
<td>81.58</td>
<td>89.82</td>
</tr>
<tr>
<td>MVV (L/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>153.31</td>
<td>92.18</td>
<td>119.96</td>
</tr>
<tr>
<td>SD</td>
<td>1.04</td>
<td>18.50</td>
<td>37.53</td>
</tr>
<tr>
<td>Mean % predicted</td>
<td>88.76</td>
<td>68.65</td>
<td>78.71</td>
</tr>
</tbody>
</table>

$VO_2$ 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 ($VO_2$ max) following a progressive workload. Measurement of $VO_2$ max is a well-established and valid indicator of cardiovascular fitness (American College of Sports Medicine, 2000). For the $VO_2$ max test, the participant maintained a constant speed as the resistance on the bicycle was gradually increased. The participant’s $VO_2$ 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: 1) achieved age-predicted maximum heart rate, 2) $O_2$ consumption leveled off despite an increase in resistance/workload, 3) $O_2$ consumption decreased despite an increase in resistance/workload, 4) respiratory quotient greater than 1.1. Table 3 displays the mean and standard deviation of $VO_2$ max values.
Table 3

\( VO_2 \) max Values

<table>
<thead>
<tr>
<th>Participants</th>
<th>VO2 max values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>44.60</td>
</tr>
<tr>
<td>SD</td>
<td>8.14</td>
</tr>
<tr>
<td>Females</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>45.57</td>
</tr>
<tr>
<td>SD</td>
<td>6.49</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>45.09</td>
</tr>
<tr>
<td>SD</td>
<td>7.04</td>
</tr>
</tbody>
</table>

Measures of \( O_2 \) consumption were obtained from a nasal-oral facemask (7400 Series Face Mask, Hans Rudolph) connected to a metabolic cart. The nasal-oral facemask does not require the typical snorkel-like mouthpiece used in \( VO_2 \) testing. This mask was used for all tasks in this study. Heart rate was continuously monitored throughout the testing with a Polar monitor (Polar Electro, Finland), and \( O_2 \) consumption levels were collected and analyzed via open-circuit spirometry, using a Parvomedics System (Sandy, Utah).

Experimental Work Tasks

The overall design of this study required each participant to perform four separate experimental tasks. Two of the tasks involved the participant working without speaking at either 50% of \( VO_2 \) max or 75% of \( VO_2 \) max. The other tasks were also performed at 50% of \( VO_2 \) max or 75% of \( VO_2 \) max, but the participant was asked to speak while working. The condition of the 50% of \( VO_2 \) max is considered to be a moderate work intensity, while 75% of \( VO_2 \) max is considered to be a high work intensity. The order of the four tasks was randomized, and half of the participants performed the two moderate intensity tasks first with the other half performing the two high intensity tasks first.

Non-Speech Tasks. For the non-speech tasks, baseline measures of heart rate and sensation of dyspnea (quantified through corresponding values on a Borg scale; Figure 2) were recorded while at rest. Next, the participant was instructed to begin the test by completing a rest-to-work transition period, which lasted for a mean of 4.9 minutes (SD = 1.9) during the moderate work task and for a mean of 6.9 minutes (SD = 1.7) for the
higher intensity task. During the transition period, the investigator set the bicycle to the appropriate tension while coaching the participant to complete a specified number of revolutions per minute in order to achieve a stable work intensity of either 50% of VO$_2$max or 75% of VO$_2$max (to be completed on separate days). Once the participant was stabilized at the specified percentage of VO$_2$max, the participant’s heart rate and Borg value were recorded (Time 1). The same values were again obtained 3 minutes later (Time 2) and 6 minutes later (Time 3).

Figure 2

*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>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<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>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<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>
</tr>
</tbody>
</table>

*Simultaneous Speech and Work Tasks.* Prior to beginning each of the simultaneous speech and work tasks, the participant was asked to rate his or her sensation of dyspnea by pointing to a corresponding number on the Borg scale (Figure 2). Next, the participant was asked to read the Rainbow Passage (a standard reading passage used in speech science research; Appendix B; Fairbanks, 1960) with the facemask on. All reading materials were placed directly in front of the participant, and the text for these passages was printed in a large enough font to ensure ease of reading. Only the baseline
reading, Time 1, Time 2, and Time 3 readings of the Rainbow Passage were analyzed for the number of inappropriately placed pauses and the words per phrase. Speech production was recorded using a unidirectional microphone connected to a digital tape recorder (TASCAM, SONY). The microphone is highly sensitive, and noise produced from the bicycle, while in use, did not interfere with the recordings. The recording samples were digitized for analysis using Adobe Audition 1.0 software.

After the completion of the initial baseline reading, the participant was instructed to perform the rest-to-work transition period in order to be stabilized at the appropriate work level. The rest-to-work transition period lasted for a mean of 4.9 minutes (SD = 2.3) for the moderate work load and for a mean of 6.5 minutes (SD = 1.8) for the task performed at 75% of VO\textsubscript{2} max. The simultaneous speech and work tasks followed the same procedures as the non-speech task, except that once the participant was stabilized and working at either 50% of VO\textsubscript{2} max or 75% of VO\textsubscript{2} max, the participant was given 15 seconds to rate his or her dyspnea using the Borg scale. During the 15-second interval the participant’s heart rate was recorded as well. After the two values were recorded and the 15 seconds had passed, the participant was instructed to read the Rainbow Passage. Individual participants attempted to maintain a normal speaking rate, yet if they increased their rate of speaking, all subjects complied with the instructor’s signal to keep their rate constant. Upon completion of the Rainbow Passage, the participant continued reading other standard, phonetically balanced passages (Appendix C) until 3 minutes passed from the end of the rest-to-work transition period (Time 1). At that time, 15 seconds was allotted to record heart rate and the Borg value before the participant began reading for the next 2 minutes, 45 seconds (Time 2). Time 3 was the last recording of heart rate, Borg value, and the Rainbow Passage.

Statistical Analysis

Multiple repeated measures analyses of variance (ANOVA) were used to determine if significant differences existed among the parameters of heart rate and Borg ratings during all four tasks. Repeated measures ANOVAs were also performed to examine values of heart rate, Borg rating, number of inappropriate pauses, and words per phrase over time in order to determine the presence of an interaction of speech during the moderate and high intensity simultaneous speech and work tasks. A multiple regression
analysis examined the influence of initial VO$_2$ max of each participant on the dependent variables at Time 3 (end of task) during an absolute work load. A significant difference level was accepted if $p < 0.05$. 
CHAPTER IV

Results

Descriptive Analysis

The means and standard error of the means for heart rate and Borg values during all four experimental tasks are displayed in Tables 4 and 5 and Figures 3 and 4. The number of words per phrase and the number of inappropriate pauses during all speaking tasks are displayed in Tables 6 and 7 and Figures 5 and 6.

Table 4

*Heart Rate (beats per minute) during All Tasks*

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% Non-speaking</td>
<td>Mean 78.25</td>
<td>140.67</td>
<td>146.50</td>
<td>148.75</td>
</tr>
<tr>
<td></td>
<td>SE 4.10</td>
<td>2.38</td>
<td>3.28</td>
<td>3.95</td>
</tr>
<tr>
<td>50% Speaking</td>
<td>Mean 79.83</td>
<td>138.83</td>
<td>145.75</td>
<td>151.67</td>
</tr>
<tr>
<td></td>
<td>SE 2.68</td>
<td>2.88</td>
<td>2.80</td>
<td>2.91</td>
</tr>
<tr>
<td>75% Non-speaking</td>
<td>Mean 79.42</td>
<td>163.83</td>
<td>172.33</td>
<td>174.25</td>
</tr>
<tr>
<td></td>
<td>SE 1.76</td>
<td>2.99</td>
<td>2.50</td>
<td>2.02</td>
</tr>
<tr>
<td>75% Speaking</td>
<td>Mean 74.67</td>
<td>164.50</td>
<td>171.58</td>
<td>176.00</td>
</tr>
<tr>
<td></td>
<td>SE 2.99</td>
<td>4.46</td>
<td>4.19</td>
<td>3.46</td>
</tr>
</tbody>
</table>

Table 5

*Borg Values for Ratings of Perceived Breathlessness during All Tasks*

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% Non-speaking</td>
<td>Mean 0</td>
<td>1.80</td>
<td>2.20</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>SE N/A</td>
<td>0.26</td>
<td>0.30</td>
<td>0.27</td>
</tr>
<tr>
<td>50% Speaking</td>
<td>Mean 0</td>
<td>1.70</td>
<td>3.20</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td>SE N/A</td>
<td>0.20</td>
<td>0.21</td>
<td>0.23</td>
</tr>
<tr>
<td>75% Non-speaking</td>
<td>Mean 0</td>
<td>3.10</td>
<td>4.00</td>
<td>4.70</td>
</tr>
<tr>
<td></td>
<td>SE N/A</td>
<td>0.46</td>
<td>0.51</td>
<td>0.59</td>
</tr>
<tr>
<td>75% Speaking</td>
<td>Mean 0</td>
<td>3.00</td>
<td>4.70</td>
<td>6.30</td>
</tr>
<tr>
<td></td>
<td>SE N/A</td>
<td>0.51</td>
<td>0.59</td>
<td>0.54</td>
</tr>
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</table>
Table 6

Number of Words per Phrase during All Speaking Tasks

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>50% Speaking</strong></td>
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<td></td>
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<tr>
<td>Mean</td>
<td>13.58</td>
<td>8.53</td>
<td>9.30</td>
<td>9.95</td>
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<tr>
<td>SE</td>
<td>0.63</td>
<td>0.54</td>
<td>0.70</td>
<td>0.89</td>
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<tr>
<td><strong>75% Speaking</strong></td>
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<td></td>
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<tr>
<td>Mean</td>
<td>15.48</td>
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<tr>
<td>SE</td>
<td>0.63</td>
<td>0.42</td>
<td>0.81</td>
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</table>

Table 7

Number of Inappropriate Pauses during All Speaking Tasks

<table>
<thead>
<tr>
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<th>Baseline</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>50% Speaking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.17</td>
<td>0.75</td>
<td>0.67</td>
<td>0.58</td>
</tr>
<tr>
<td>SE</td>
<td>0.11</td>
<td>0.25</td>
<td>0.23</td>
<td>0.29</td>
</tr>
<tr>
<td><strong>75% Speaking</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.17</td>
<td>2.25</td>
<td>1.92</td>
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<tr>
<td>SE</td>
<td>0.11</td>
<td>0.58</td>
<td>0.44</td>
<td>0.78</td>
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</tbody>
</table>

Figure 3

Average Heart Rate during All Tasks

![Heart Rate Graph](image)
Figure 4

*Average Borg Scale Ratings during All Tasks*

![Graph showing average Borg Scale Ratings during all tasks.](image)

Figure 5

*Average Words per Phrase*

![Graph showing average words per phrase.](image)
Inter-rater reliability

Because appropriate placement of pauses could be perceived as a subjective measure, two undergraduate students in the Department of Speech Pathology and Audiology were utilized to complete inter-rater reliability measures on 10% of the samples. There was no statistical difference among the samples measured for the number of words per phrase, $t = .016, p = .988$, and for the number of inappropriate pauses, $t = .533, p = .597$.

Intra-rater reliability

The investigator remeasured 10% of the samples for intra-rater reliability purposes. No significant difference was revealed for the number of words per phrase, $t = -.335, p = .740$, and for the number of inappropriate pauses, $t = .212, p = .833$. 

Figure 6

*Average Number of Inappropriate Pauses*
**Inferential Analysis for Research Questions**

**Research question 1:**

Do heart rate and dyspnea ratings during a simultaneous speech and work task differ significantly compared to a non-speech work task of similar intensity?

A repeated measures analysis of variance (ANOVA) with time, intensity (either 50 or 75% of VO$_2$ max), and the specific task type (either speaking or non-speaking) as within-subject factors was completed. The results revealed a significant main effect for task type $F(1, 127) = 0.82, p = .367$. Post-hoc analyses using t-tests revealed no significant difference in heart rate between the two specific task types at 75% of VO$_2$ max, $t(1) = 1.33, p = .273$, or at 50% of VO$_2$ max, $t(1) = 1.82, p = .180$.

To determine the difference in Borg scale rating of perceived dyspnea across the four experimental tasks, a repeated measures ANOVA with the same aforementioned factors was completed. There was a significant main effect of speaking, $F(1, 123) = 4.98, p = .008$. Post-hoc analysis using t-tests revealed a significant difference in Borg ratings between the two specific task types at 50% of VO$_2$ max, $t(1) = 17.62, p = .001$, or at 75% of VO$_2$ max, $t(1) = 7.11, p = .022$.

**Research questions 2 and 3:**

Do heart rate, dyspnea ratings, and speech parameters differ significantly from baseline during a simultaneous speech and work task, and do heart rate, dyspnea ratings, and speech parameters differ significantly between a simultaneous speech and work task performed at 50% of VO$_2$ max compared to the same task at 75% of VO$_2$ max?

Repeated measures ANOVAs were utilized to determine differences among the dependent variables between the two intensity levels of the speaking tasks. Statistically significant differences in heart rate, $F(1, 57) = 323.02, p = .0001$, Borg values, $F(1, 57) = 85.12, p = .0001$, the number of words per phrase, $F(1, 59) = 82.14, p = .0001$, and the number of inappropriate pauses, $F(1, 59) = 23.47, p = .0001$ were found between speaking at 50% of VO$_2$ max and speaking at 75% VO$_2$ max. Significant differences were found between baseline and an average of Times 1 through 3 for all of the dependent measures. See Table 8.
Table 8

*T-tests for an Average of Times 1 through 3 Values Compared to Baseline*

<table>
<thead>
<tr>
<th>Measure</th>
<th>Times 1 through 3</th>
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<tbody>
<tr>
<td></td>
<td>t</td>
</tr>
<tr>
<td>Heart Rate</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>54.65</td>
</tr>
<tr>
<td>75%</td>
<td>80.03</td>
</tr>
<tr>
<td>Borg</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>16.41</td>
</tr>
<tr>
<td>75%</td>
<td>29.41</td>
</tr>
<tr>
<td>Words per phrase</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>-11.62</td>
</tr>
<tr>
<td>75%</td>
<td>-24.49</td>
</tr>
<tr>
<td>Inappropriate Pauses</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>2.75</td>
</tr>
<tr>
<td>75%</td>
<td>9.71</td>
</tr>
</tbody>
</table>

**Research question 4:**

*Does an individual’s VO\textsubscript{2} max influence sensation of dyspnea, words per phrase, and use of inappropriate pauses when measured after six minutes of physical work?*

Ten participants were working at a rate of O\textsubscript{2} consumption within the range 22-28 ml/kg/min when performing the simultaneous speech and work task at either 50% of VO\textsubscript{2} max or 75% VO\textsubscript{2} max. All 10 participants were performing the task at a similar work load level (not relative to their own VO\textsubscript{2} max). A multiple regression analysis illustrated VO\textsubscript{2} max as a significant predictor for Borg scale ratings, $\beta = .079$, $t(6) = -2.60$, $p = .041$ and words per phrase, $\beta = .166$, $t(6) = 3.02$, $p = .024$, but did not significantly predict the number of inappropriate pauses, $\beta = .092$, $t(6) = -.020$, $p = .987$.

The 10 participants were chosen for an absolute work load analysis based upon their overall fitness level as measured by their VO\textsubscript{2} max. Eight of the participants performed the speaking task at 50% of VO\textsubscript{2} max in order to be within the absolute work load, and two were working at 75% of VO\textsubscript{2} max. The other two participants had VO\textsubscript{2} max values of 39.3 and 39.2 mL/kg/min, which placed them outside of the range for the absolute work load. During the moderate intensity work task, these two participants were working at approximately 19.7 mL/kg/min, and at the higher intensity level, they were
working at 29.5 mL/kg/min. In order to be able to make assumptions regarding an individual’s ability to improve his/her performance during a simultaneous speech and work task, all participants had to be working at an absolute work load relative to his/her own VO$_2$ max value. If an individual is more physically fit, then he/she will likely have greater success at maintaining speech fluency and at controlling the respiratory system’s response to increased dyspnea ratings as compared to an individual who is not as physically fit (i.e., has a lower VO$_2$ max value).
CHAPTER V
Discussion

Background

The present study examined specific speech parameters at two different intensity levels of a physical work task and at specific time intervals during the task to describe how speech differs from baseline and between the two intensity levels. Previous research in the area of simultaneous speech and physical work (Doust and Patrick, 1981; Meckel et al., 2002) demonstrated that ventilation decreased during a simultaneous speech and work task compared to non-speech work tasks. During performance of a simultaneous speech and work task, the respiratory system is temporarily forced to provide O$_2$ to the working muscles concurrently with the act of speaking. However, an imbalance between O$_2$ and CO$_2$ occurs because speech takes precedence and control of the respiratory system as is noted in the form of inspiratory checking. The rate of airflow as it exits the lungs is depressed by the active contraction of the muscles of inspiration. Thus, the expiratory phase dominates, and less O$_2$ is inspired for transportation to the working muscles, and ventilation in turn decreases as well.

When O$_2$ levels decrease substantially, the respiratory control center signals the muscles of respiration to take an inspiration immediately. The need to inspire interferes with the breathing pattern associated with speaking (i.e., the expiratory phase dominates during speaking tasks). Therefore, for the present study it was assumed the number of words per phrase would decrease and the number of inappropriate pauses would increase particularly at the higher work intensity level and as the work tasks continued. Values of heart rate, sensation of breathlessness as determined by a Borg scale rating were also obtained in order to examine an increase in fatigue that might result from performing a simultaneous speech and work task compared to performing the physical work task independently. With the knowledge that individuals with greater VO$_2$ max values are better able to transport O$_2$ to the working muscles (ACSM, 2000), and therefore have an overall lower ventilation rate, it was hypothesized individuals in the present study who had higher VO$_2$ max values would have lower ratings on the Borg scale as well as greater speech fluency as indicated by a greater number of words per phrase and fewer inappropriate pauses due to a decreased need to inspire during the task.
Research question 1:

Do heart rate and dyspnea ratings during a simultaneous speech and work task differ significantly compared to a non-speech work task of similar intensity?

While performing the task at the higher intensity level, participants demonstrated significantly greater values for heart rate and Borg scale ratings. Furthermore, when speech was added to the physical work task, participants did not show a significant difference in heart rate values, but they did have significantly greater Borg scale values during the simultaneous speech and work task. The main effect seen in the dyspnea ratings between the two task types was significantly greater at the higher intensity task as compared to the moderately intense task.

Heart rate and Borg scale ratings are valuable measures in determining overall work level and feelings of discomfort during a physical work task. The results of the present study yielded a significant difference in heart rate between the two intensity levels, which was expected, given that a physical work task performed at 75% of VO\textsubscript{2} max is more challenging than a physical work task performed at 50% of VO\textsubscript{2} max. During the higher intensity work task, more active recruitment from the working muscles is needed in order to sustain the activity. Therefore, the heart rate will increase as more oxygenated blood is transported to the working muscles (Powers & Howley, 2004). Furthermore, in order to oxygenate the blood, the respiratory system is responsible for inspiring enough air from the immediate environment. Participants in the present study reported higher Borg scale ratings during the higher intensity work task due to the fact they felt a greater sensation of breathlessness as ventilation decreased and as the body continued to demand O\textsubscript{2}, requiring the respiratory system to work harder to meet the O\textsubscript{2} demand. The greater demands and physical strain placed on the body during the higher intensity work task equated to an increased sensation of dyspnea among the participants, which was reflected in their reported Borg values, as expected.

Although the participants had a noted difference in heart rate among the two intensity levels, heart rate was not affected when speech was added. Participants were able to adapt to the increased heart rate during the speaking tasks by making the necessary adjustments in their speech fluency. Both voluntary respiratory tasks (speaking and working) compete for control of the respiratory system. In the present study, the
work load remained constant. Therefore, in order to attempt to complete the tasks, participants altered their speech fluency. While performing the simultaneous speech and work task, and when compared to the baseline readings taken while at rest, participants used fewer words per phrase and more inappropriate pauses when working at the higher intensity level. By making these alterations in speech fluency, the participants succeeded in not allowing their heart rate to increase above levels noted during non-speaking tasks.

Even though the participants were able to control their heart rate while speaking, they demonstrated a significant difference in their sensation of breathlessness during a similar task type. As seen in previous studies (Doust and Patrick, 1981; Meckel et al., 2002), ventilation decreases when speaking during a physical work task. The lack of O\textsubscript{2} being transported to the working muscles is perceived in the cortex as air hunger and the sensation of effort by the working respiratory muscles. The air hunger signals the body that more O\textsubscript{2} is needed for metabolic functions, which in turn triggers the respiratory system to focus on inspiration as opposed to expiration for speech. Furthermore, during speech, the muscles of inspiration remain in a contracted state in order to control the rate of airflow as it is exiting the lungs in order to ensure proper voicing (inspiratory checking). Thus, not only are the muscles of inspiration required to contract while speaking, they are still responsible for bringing air into the lungs to be transported to the blood to supply the other muscles working in the body to perform the physical work task. The two tasks (inspiratory checking and adequate inspirations for O\textsubscript{2} transport to the working muscles) are indirectly causing inspiratory muscle fatigue. The effects of the fatiguing inspiratory muscles was reflected in the higher Borg scale ratings given by the participants, which was expected due to the increased sensation of air hunger.

Research questions 2 and 3:

Do heart rate, dyspnea ratings, and speech parameters differ significantly from baseline during a simultaneous speech and work task, and do heart rate, dyspnea ratings, and speech parameters differ significantly between a simultaneous speech and work task performed at 50% of VO\textsubscript{2} max compared to the same task at 75% of VO\textsubscript{2} max?

All dependent measures differed significantly from baseline during a simultaneous speech and work task. Heart rate, dyspnea ratings, and the number of
inappropriate pauses were significantly greater than baseline measures, and the number of words per phrase was significantly less than baseline measures during a simultaneous speech and work task. The higher intensity work task of 75% of VO\textsubscript{2} max was significantly more challenging than the moderately intense task of 50% of VO\textsubscript{2} max. Heart rate, Borg scale ratings, the number of words per phrase, and the number of inappropriate pauses differed significantly between the two intensity levels, with the dependent measures being statistically greater at the higher intensity task level as compared to the moderate intensity task level.

Given that previous research demonstrated that ventilation decreases during a simultaneous speech and work task (Doust and Patrick, 1981; Meckel et al., 2002), it was expected the respiratory system would experience greater challenges in maintaining a proper O\textsubscript{2}/CO\textsubscript{2} balance at the higher intensity level (75% of VO\textsubscript{2} max). Heart rate increases in order to continue supplying the working muscles with the limited amount of O\textsubscript{2} entering through the lungs, which was demonstrated through the participants’ significantly higher heart rate during the simultaneous speech and work task performed at the higher intensity level compared to the moderate level. Furthermore, as the speech and work task continued at the higher intensity level as opposed to the moderate intensity level, and as ventilation decreased, air hunger increased. Respiratory effort and the sensation of breathlessness became increasingly stronger as well. Participants’ demonstrated their increasing discomfort through values on a Borg scale. Borg scale values were statistically greater at the higher intensity level of 75% of VO\textsubscript{2} max compared to their values recorded during the task performed at 50% of VO\textsubscript{2} max.

Decreasing ventilation, rising heart rate, and increasing discomfort through O\textsubscript{2} deprivation eventually adversely affected speech fluency at the higher intensity level compared to the moderate intensity level. It was evident through a significant decrease in words spoken per phrase along with a significant increase in the occurrence of inappropriate pauses (as compared to baseline values) that speech became more difficult at the higher work load of 75% VO\textsubscript{2} max when compared to the moderate intensity level. During the higher intensity physical task, the respiratory system struggles to regain a vital balance between O\textsubscript{2} and CO\textsubscript{2} within the body. Insufficient O\textsubscript{2} is being supplied to the working muscles, and at some point the imbalance becomes too great and the working
muscles become fatigued. At that point, speech no longer retains control of the respiratory system, as was evidenced in the present study through fewer words spoken per phrase as well as through a greater number of inappropriate pauses used. Speech was no longer fluent at Time 3 as it had been during baseline measurements, and the longer the task continued, the more dysfluent speech became.

Research question 4:

Does an individual’s VO$_2$ max influence sensation of dyspnea, words per phrase, and use of inappropriate pauses when measured after six minutes of physical work?

There was a direct relationship between an individual’s VO$_2$ max value and the likelihood that he/she was able to complete the simultaneous speech and work task with fewer disruptions in the respiratory system that adversely affect speech fluency. Participants with higher VO$_2$ max values maintained greater speech fluency throughout the simultaneous speech and work task as compared to participants with lower VO$_2$ max values.

VO$_2$ max is a widely used measure to indicate overall physical fitness levels (ACSM, 2000). Higher VO$_2$ max values equate to the individual’s greater capacity to transport O$_2$ more efficiently to working muscles during physical activity (ACSM, 2000; Powers & Howley, 2004). Lower ventilation rates in general are seen in individuals with higher VO$_2$ max values (ACSM, 2000). In the present study, it was hypothesized VO$_2$ max would influence the participant’s ability to carry more O$_2$ to the working muscles at a lower ventilation rate during the speech tasks completed at an absolute intensity level. It was believed individuals with greater VO$_2$ max values would have an advantage over other participants in transporting O$_2$ to the working muscles in the body. This advantage would thereby decrease the participants with the higher VO$_2$ max values sensation of dyspnea and overall respiratory muscular effort.

The analysis indicated that VO$_2$ max level influences measures of breathlessness and the number of words per phrase after 6 minutes of simultaneous speech and physical work. These results suggest that, therefore, the greater an individual’s VO$_2$ max value is, the more likely he/she is able to complete the simultaneous speech and work task with fewer disruptions in the respiratory system that adversely affect speech fluency.
Limitations

Limitations to the study surfaced in regards to the various work task protocols. Given that significant changes were seen among the dependent variables during the simultaneous speech and work tasks, it would be interesting to examine how the variables would be affected if they were required to continue performing the task longer than 6 minutes. It would also be interesting to examine the dependent variables in a task in which participants were told to keep working as long as they were able to do so. It is likely that an individual’s VO$_2$ max would have a significant influence on the overall length of the task. It is assumed that an individual with a greater VO$_2$ max value would be able to continue working longer than someone with a lower VO$_2$ max value (ACSM, 2000).

Another limitation in this study was the inability to directly measure ventilation values during speech production. The metabolic cart hardware and software program used in the present study detected each speech aspiration (a manner of articulation involving an audible release of breath) as a separate expiration. Therefore, direct comparisons of breathing during the two speaking tasks could not be analyzed. Future studies would benefit from utilizing a measurement system that would allow for the analysis of each breath and not the individual speech aspirations. A system that allows for breath-by-breath analysis would provide information about various respiratory parameters, such as breaths per minute and tidal volume in order to ascertain that the participants are indeed performing the simultaneous speech and work task with a lowered ventilation rate.

Future Research

Given that Doust and Patrick (1981) and Meckel et al. (2002) showed a decrease in ventilation during a simultaneous speech and work task, it would be interesting to determine if the decreased ventilation equates to requiring that the individual continue performing the task in an anaerobic state. The anaerobic energy system is best suited for shorter, more intense bouts of physical work (Powers & Howley, 2004). The fuel supplies of phosphocreatine and glycogen, which are utilized in an anaerobic state, are limited and therefore cannot be utilized during work tasks of long duration. Fatigue will
likely increase, thereby causing the individual to make necessary alterations to his/her performance of the specific task type.

During a simultaneous speech and work task it is suspected individuals must rely on their anaerobic energy system at some point during the task given that studies have shown ventilation decreases while speaking and working simultaneously. To determine when the participants are working in an anaerobic state, future studies might measure blood lactate levels to further indicate that ventilation has indeed decreased during the simultaneous speech and work tasks. Information on blood lactate levels would provide further evidence as to the interval of time in which the individual is performing the physical work task in an anaerobic state. Blood lactate levels could also be obtained during the non-speaking tasks in order to make direct comparisons between the two specific task types at the two intensity levels.

Another valuable indicator of physical work being performed in an O₂ depleted state is the respiratory exchange ratio (RER). This ratio is defined as the amount of CO₂ produced divided by the amount of O₂ consumed (Powers & Howley, 2004). At rest, the RER ranges from 0.7 to 0.85, and this value provides an indirect measure of the predominant fuel utilized for cellular metabolism (Pina, Balady, Hanson, Labovitz, Madonna, & Myers, 1995). When the RER nears 1.0, CO₂ exceeds VO₂ (the rate at which O₂ is consumed by a tissue within the body). It is at this point, typically during a high intensity work task, that an individual begins to reach his/her near-maximal level of effort, and may further indicate how soon the individual is likely to fatigue and/or cease performing the task.

It would also be of interest to analyze how long an individual needs to cease either speaking and/or working before resuming the two tasks again. It is likely that individuals with higher VO₂ max values will not need as long of a recovery time as an individual who is less physically fit, as these individuals are able to transport more O₂ to the working muscles at a faster rate during a recovery period. Professionals required to speak while doing physical work would likely be interested in future knowledge of recovery times.

Professionals who are required to speak while completing physical work may also be interested in the potential influence of VO₂ max on speaking ability. Overall physical
fitness levels were shown to influence dyspnea and words per phrase in the present study. Therefore, if an individual is able to improve his/her fitness level, then he/she is likely to exhibit greater speech fluency during the two specific tasks types. However, professionals who are already required to speak while performing a physical work task are likely at the high end of their potential fitness level (i.e., aerobics instructors, military drill instructors). Yet, it may still be possible to improve their ability to complete a simultaneous speech and work task with clear, fluent speech through use of inspiratory muscle strength training.

The inspiratory muscles are responsible for the larger volume inspirations associated with physical work tasks. Contraction of inspiratory muscles is also necessary to control the rate of airflow as it exits the lungs to ensure appropriate voicing (particularly when large volumes are inspired). With increased inspiratory muscle strength, it is assumed those individuals will not fatigue or experience dyspnea as quickly, and may likely have greater speech fluency as measured by an increase in the number of words per phrase and a decrease in the number of inappropriate pauses.

Previous studies have examined various mechanisms by which individuals may work to increase their inspiratory muscle strength. Volianitis, McConnell, Koutedakis, McNaughton, Backx, & Jones (2001) examined the effects of inspiratory muscle training (IMT) in 14 female rowers, who were all either national team members or candidates for the national team and had been competing for a minimum of 3-4 years. Seven of the participants formed the training group and were required to perform the inspiratory muscle training by inspiring against a resistance equivalent to 50% peak inspiratory mouth pressure (PImax) for 30 inspiratory efforts twice daily. The placebo group trained by inspiring against 15% PImax for 60 breaths once daily. The training group increased their overall inspiratory muscle strength by a mean of 44 cmH₂O compared to a mean increase of only 6 cmH₂O in the control group. Rowing performance improved in the training group as compared to the placebo group such that during a 6-minute all-out effort, the distance covered increased by 3.5 +/- 1.2% in the training group. The placebo group improved their distance covered by only 1.6 +/- 1.0%. Furthermore, the training group decreased their time in a 5000-m trial by 36 +/- 9 seconds (3.1 +/- 0.8%), whereas the placebo group decreased their time by only 11 +/- 8 seconds (0.9 +/- 0.6%).
Therefore, it can be concluded inspiratory muscle training can improve the performance of female rowing athletes by increasing the distance covered in a 6-minute all-out effort and by decreasing the time needed to complete a 5000-m trial.

Another similar study utilized 17 competitive male cyclists in order to evaluate the effects of an inspiratory muscle training (IMT) program (Sonetti, D.A., Wetter, T.J., Pegelow, D.F., & Dempsey, J.A., 2001). The training lasted 5 weeks and included 25 sessions. Nine subjects participated in the IMT as well as inspiratory resistive strength training. The 8 subjects in the placebo group were asked to train using a placebo breathing device similar in appearance to the resistance training device. Results indicated a significant 8% increase in maximum inspiratory pressure (MIP; the dependent variable used to measure inspiratory muscle strength) from 168.5 +/- 39.8 to 181.4 +/- 40.4 cmH\textsubscript{2}O \((p < .05)\) in the training group. The placebo group only showed a 3.7% increase in MIP. Increases in their fixed work-rate endurance test performance times were +26% and +16% for the RMT group and the placebo group, respectively. The IMT group significantly improved their 8 km time trial scores by 1.8% +/- 1.2%, and the placebo group improved their times by only –0.3 +/- 2.7%. Lastly, VO\textsubscript{2} max values improved significantly in the IMT group (+9%) and in the placebo group (+6%). Although greater improvements were noted in the IMT group as compared to the placebo group, there was no statistical significance between the two groups, which indicates that in well-trained cyclists, the effect of IMT on their exercise performance is not significantly greater than a similarly matched placebo group. However, given a larger sample size, the noted trends in improved scores of the three performance tests could prove to be significantly greater in the IMT group as compared to the placebo group, which would further illustrate the benefits of inspiratory muscle strength training to improve an individual’s performance of various physically demanding work tasks.

Further studies have documented the increases in MIP through the use of a resistive trainer in patients with upper airway obstructive disorder. Baker, Sapienza, Martin, Davenport, Hoffman-Ruddy, & Woodson (2003) and Sapienza, Brown, Martin, & Davenport (2003) found overall improvement in MIP in the participants selected for the studies. Maximum inspiratory pressure increased significantly among the participants selected for the studies, and dyspnea measures during separate exercise and speaking
tasks were significantly lower in the participants post-training. The individuals selected to participate in these studies had breathing problems, which equated to increased dyspnea during a simultaneous speech and physical work task. Given that certain individuals with upper airway obstructive disorder have physical limitations that prevent them from improving their VO$_2$ max through physical exercise programs, it is hypothesized that IMT will significantly reduce the sensation of dyspnea of these individuals during a simultaneous speech and physical work task.

Chapter Summary

This chapter outlined the results of the present study. Conclusions, limitations, and future research options were discussed as well. It was concluded that heart rate and sensation of dyspnea increased during a higher intensity simultaneous speech and work task as compared to a moderately intense task. Speech fluency was negatively impacted during the task performed at 50 and 75% of VO$_2$ max, and speech became less fluent the further into the task as compared to speech fluency at baseline. The limitations of the present study should be taken into consideration when interpreting the results. However, future research options discussed in this chapter will likely augment the results of the present study.
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metabolic and behavioral respiratory control during hypercapnia and speech.


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:
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.
Appendix C:
Additional Phonetically Balanced Reading Passages

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.

Papa Passage

Papa was a great man. Working all of his life as a carpenter, he built homes for other people. Papa was an excellent craftsman. Anyone who worked with Papa knew that he was an honest man. Papa gave himself to his work, toiling daily for small amounts of money. No one disliked Papa. In fact, neighbors used to bring Papa apples, pears, and other fruits, especially around the holidays. I remember Papa for his kind ways. What I remember was the manner in which Papa dressed, the way he carried himself. Papa was such a strong man. Devoted to his family, especially his children, Papa worked night and day to provide for us. Although we never showed Papa our appreciation on a daily basis, I know that he felt our love, or so I hope.

The 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.