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# Are Respiratory Behaviors Affected In Individuals With Adductor Spasmodic Dysphonia?

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
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# Dedication

I would like to dedicate this thesis to my family.  Mom and Dad, your unyielding encouragement and unconditional love provided me the support to pursue this degree and complete this study. Scott and Julie, thank you for believing in me and reassuring me whenever I needed it.  Millicent, without your constant companionship, this journey would have been a lonely one.

Katie Biedess

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# Are Respiratory Behaviors Affected In Individuals With Adductor Spasmodic Dysphonia?

Katie Biedess

## ABSTRACT

Adductor spasmodic dysphonia (ADSD) is a focal dystonia that is characterized by voice breaks due to involuntary contractions of the adductor muscles of the vocal folds. These spasms can interfere with the coordination and balance of the respiratory and phonatory systems interfering with normal voice production. Disruptions in normal respiratory behaviors are well documented in inviduals with laryngeal disorders, including ADSD. Previous research regarding respiratory processes in ADSD has focused on airflow and pressure; however, there are many other parameters that have not been considered and may shed new light on the respiratory behaviors of individuals with ADSD. Therefore, the current pilot study attempted to determine if individuals with ADSD differed from controls in various breathing parameters while engaged in conversational and reading tasks.

Thirty individuals were tested; fifteen in the ADSD group and fifteen in the age- and gender-matched control group. Respitrace, an inductive plethysmography device, calculated 14 different respiratory measures related to volume, timing, thoracic displacement and respiratory efficiency. The results of the study indicated that various significant differences existed between groups. Those with ADSD were found to have statistically higher ventilation rates, a greater frequency of breaths per minute, a higher degree of muscular inefficiency/breathlessness and labored breathing. These results indicated that individuals with ADSD suffered from disordered breathing due to the neurologically related obstruction at the level of the larynx.

Differences according to task were also found. Specifically, the rib cage contributed to a lesser extent in voice production and the participants utilized longer inspiratory times, exhaled a larger volume of air and took longer to reach peak expiratory flow during conversational tasks when compared to reading tasks. These differences were attributed to a higher cognitive-linguistic demand required during conversational speech. Overall, the results of this study have many clinical implications. Most importantly, these findings support the idea that individuals with ADSD may experience difficulties with respiration as the effects of their Botox injection begin to wear off. Further research is needed with regards to the effects laryngeal spasms have on other respiratory behaviors.

# Introduction

The process of respiration is multifaceted and intricate. It requires the coordination of various structures and muscles to function appropriately. The rib cage and the abdomen are the two basic structures that assist in respiration (Hixon, Goldman, & Mead, 1973). These two areas of the body work together (and typically move as a unit) to facilitate lung expansion and contraction, which results in a physical displacement of the thoracic cavity. Total rib cage and abdominal displacement are equal to the total lung volume change; i.e., the amount of air that is inhaled or exhaled (Hixon et al., 1973). In other words, the volume of air that is inhaled and exhaled on a single breath is directly related to the physical movement of these two structures.

The rib cage is a highly developed region. It encases the lungs, which are held to the interior of the rib cage by pleural forces. The rib cage expands and contracts through the influence of muscle contraction and external/internal pressures (Hixon et al., 1973). Inspiratory muscles, such as the external intercostals, contract and lift the rib cage superiorly, anteriorly and horizontally. Because the lungs are attached to the rib cage, they also expand. This expansion creates a negative internal lung pressure when compared to the external environmental positive pressure. This results in a rush of air into the lungs (Hixon et al., 1973). This process can be likened to the effects of a vacuum, because air will flow from an area of positive pressure into an area of negative pressure to stabilize the environment. Exhalation works in a similar manner. Through elastic recoil of the rib cage and some muscle contraction, a positive pressure is exerted on the lungs. This pressure pushes the air out of the lungs and through the respiratory tract.

The abdomen, the second mechanism assisting in the breathing process, is comprised of the diaphragm and the muscles of the abdominal wall. The diaphragm is a muscle located at the inferior boundary of the lungs. During inhalation, the diaphragm moves downward, which in turn, pulls the lungs down and increases their size (Hixon et al., 1973). The abdominal wall is, therefore, pushed forward to allow for the downward movement of the diaphragm. This process also creates a negative pressure within the rib cage. As described above, this negative pressure facilitates air flow into the lungs.

Once the lungs fill with air, the positive pressure within the lungs triggers the process of expiration. In this process, the diaphragm relaxes, pushing the inferior edge of the lungs upward and the air outward. The abdominal muscles may also contract, pulling inward and exerting further force to move the diaphragm upward and air outward. The air that exits the lungs will proceed through the bronchi into the trachea and pass through the larynx. It is at the level of the larynx that voice production occurs. As the air reaches the level of the larynx, the vocal folds are drawn toward the midline by means of the adductor muscles. Air pressure builds up subglottally and blows the vocal folds apart. The folds are drawn back together through elastic recoil and the Bernoulli effect (Titze, 1994). This cycle of opening and closing creates a “buzz” or the complex acoustic signal known as the voice. This buzz is then carried through the vocal tract (a resonance system), going through various strictures and closures to eventually pass through the lips and/or nose. The strictures and closures along the length of the vocal tract allow for the production of consonants and vowels (or phonemes). The phonemes, when produced in sequence, create spoken words and sentences.

The production of speech, therefore, relies on the coordination and balance of three subsystems: respiration, phonation and resonance. These systems must work together as their functions often overlap. For example, one responsibility of the respiratory system is to maintain proper subglottal pressure (Haynes & Netsell, 2001), which must be regulated, as it is the foundation to voice production. The maintenance of subglottal pressure occurs through the coordination of the muscles of the respiratory system and those within the larynx (Haynes & Netsell, 2001; Redstone, 2004; Sapienza, Stathopoulos & Brown, 1997). Unfortunately, the coordination of these three systems does not always function properly. One system may be forced to act in a different fashion as a result of the other system's failure.

The respiratory system is constantly exchanging depleted air for newer, oxygen-rich air. The amount of air that is inhaled and exhaled during a single breath has been termed tidal volume. Tidal volume will change depending on the activities the individual is performing. For example, while exercising, individuals will have larger tidal volumes because more oxygen is required (Hixon et al., 1973). Similarly, tidal volume is increased for the purposes of producing speech (Hixon & Hoit, 2005). In fact, evidence has shown that people will typically inhale to about twice the resting tidal volume and expire to the resting tidal volume's end expiratory volume (Hixon & Hoit, 2005). This means, for the purposes of speech, twice the amount of air is needed than that during resting respiration.

Researchers have labeled other respiratory volumes and capacities in addition to tidal volume.  For example, the volume of air that an individual can inhale above the tidal volume is called inspiratory reserve volume, while the air that an individual can expel after the end expiratory volume of tidal volume is the expiratory reserve volume (Hixon & Hoit, 2005).  When two or more lung volumes are combined, a lung capacity is formed.  Vital capacity refers to the total amount of air a person can inhale if they exhale all of the expiratory reserve volume and then fully inhale.  Therefore, vital capacity is the sum of the expiratory reserve volume, tidal volume and the inspiratory reserve volume. For a more thorough description and explanation of lung volumes and capacities, please refer to Hixon and Hoit (2005).

## Instrumentation for Measuring Breathing

Various instruments have been used to obtain data regarding volumes, respiratory patterns, etc.  Wet spirometers were among the first instruments used to measure air volumes (Hixon & Hoit, 2005).  These instruments contained a cylindrical chamber that housed water and a floating bell.  Individuals exhaled into tubing that allowed for the expired air to become trapped under the bell, resulting in a rising of the bell.  The measurement of the air volume expelled was calculated from the distance the bell traveled.  Although innovative at the time, this instrumentation has obvious limitations. For example, it was not easily transportable to other test sites and it did not allow for measurements of expelled air during continuous speaking tasks (Hixon & Hoit, 2005).

Researchers later realized that there was a direct relationship between the physical displacement of the thorax and the resulting volume of air within the lungs (Hixon & Hoit, 2005).  Therefore, a new method to determine lung volume change was developed by measuring the changes in body surface. These instruments were developed recognizing that the volume of air is equal to the amount of chest wall and abdomen displacement (Hixon & Hoit, 2005). The magnetometer is one such instrument that establishes lung volumes through the calculation of the surface displacement. With this instrumentation, electromagnetic coiled wires are attached to the surface of the body at the sternum and above the umbilicus and at adjacent areas on the back. Magnetometers calculate the changing distance between the adjacent anterior and dorsal wires (i.e. between the sternum and the upper back and between the umbilicus and the lower back). The increasing and decreasing distances that occur during inhalation and exhalation are then converted to lung volumes (Hixon & Hoit, 2005).

Respiratory inductive plethysmography operates in a similar way. It determines lung volumes by calculating the surface displacement using elastic bands with embedded coiled wires (Hixon & Hoit, 2005). The bands are wrapped around a person's chest and abdomen and the wires calculate the expansion and contraction of the body's surface. As the body surface is displaced, the elastic transduction bands send an equivalent voltage to a calibration device, which then translates this information into volume measures (Hixon & Hoit, 2005). Because these two instruments (magnetometers and inductance plethysmography) calculate expansion and contraction of the thorax, they allow measurements to be made during inspiration and expiration.

These surface measuring devices are not without strengths and weaknesses. Due to the fact that the instruments are noninvasive, they do not restrict the respiratory or articulatory systems and allow the measurement of total lung volume change (Hixon & Hoit, 2005). Further, these instruments produce immediate measurements, which allow the study of rapid breathing processes, such as speech breathing. In comparison, instruments such as the spirometer, require the individual to exhale into a tube. This process is cumbersome due to the size of the instrument and the tubing is obstructive to normal respiratory behaviors. Further, it can only measure the volume of expired air. Spirometry does not allow measurements of inhalation because the device works by measuring the rising movements of the bell as expired air forces the bell up. On the other hand, surface-measuring devices may erroneously measure body movements that are unrelated to breathing, such as, posture changes. Also, band slippage is a possibility when using inductance plethysmography (Hixon & Hoit, 2005). Band slippage occurs when the band is too large for the person's circumference, or the Velcro fastener is loose. In these cases, distorted data may be obtained during measurements.

Respitrace (produced by Non-Invasive Monitoring Systems; Nims, 2002) is one version of inductance plethysmography. It is a commonly used instrument to determine various aspects of the breathing process. According to the manual, Respitrace is accurate to within 10% of respiratory changes when compared to other instruments that have proven to be valid measures of respiration (Nims, 2002). Like any instrument, the Respitrace is not without setbacks. A shifting baseline is an example of problems associated with this instrument (Neumann, Zinserling, Haase, Sydow, & Burchardi, 1998). When used over a period of time, the calibrated baseline of end expiratory level has been known to drift upward, possibly skewing data. A few researchers have examined this shift. For example, Neumann et al. (1998) examined the shift in individuals who were ventilator-dependent due to lung injury, Chronic Obstructive Pulmonary Disease (COPD) or sedation. The researchers found the drift did not increase or decrease at a steady rate within or between subjects. Specifically, during the first five minutes after calibration, the baselines drifted between 28.2 and 48.9 mL/min. The researchers reported that this device is, therefore, not accurate enough to make quantitative measures in lung volumes (Neumann et al., 1998). However, this finding was not supported by the data obtained in a study by Leino, Nunes, Valta, and Takala (2001), who specifically compared the newest model of Respitrace to an older version. Better measurement accuracy and maintenance of the calibration was found. These researchers made two pertinent recommendations: the instrumentation should be turned on for several hours before using on patients in order to reduce the baseline shift (maximum baseline shift during this study was under 8 mL/min) and repeated measures should be completed to assure accuracy. Overall, the researchers reported Respitrace to be “accurate enough for clinical and research purposes” (Leino et al., 2001, p. 111) even when their recommendations were not followed.

Since Respitrace has been accepted as a valid measure of the various breathing parameters (Leino et al., 2001; Nims, 2002), it has been used in a wide variety of research studies. Although commonly used for sleep apnea studies, inductance plethysmography has been used in studies related to speech production as well. Schaeffer, Cavallo, Wall and Diakow (2002) used inductive plethysmography to examine the physical respiratory movements in individuals with dysphonia. Participants were asked to read two paragraphs containing either 10- or 60-syllables per sentence. With the use of this device, the researchers were able to determine that those with dysphonia terminate speech below the resting expiratory level and used paradoxical movements in the abdomen during exhalation. They hypothesized that the dysphonic group utilized the paradoxical movements because they could not efficiently exhale due to difficulty using their abdominal muscles. The researchers assumed that the paradoxical movements would not have been so prevalent in this group if they had used more appropriate lung volumes during speaking tasks. Hence, inductive plethysmography allows for analysis of specific aspects of the breathing process, especially in the rapidly changing patterns associated with speech breathing.

Respitrace has also been used to determine the level of synchronicity between the abdomen and rib cage during respiration. Braun, Abd, Baer, Blitzer, Stewart and Brin (1995) evaluated respiratory behaviors in individuals with dystonia. Many measures of respiratory performance were used in this study including flow volume loops, inspiratory and expiratory muscle pressure, and measures of arterial blood gas values in relation to respiratory tasks (speaking and quiet breathing) and positioning (supine and sitting). Specific to the purposes of the present paper, chest wall and abdominal movements were also examined in order to determine if aberrant movements could be found during pulmonary testing while exercising. The researchers found some degree of asynchrony; however, the majority of the participants performed at near normal levels during the exercise task. On the other hand, a greater number of dystonic behaviors interrupted the breathing process while performing the other tasks (quiet breathing, speech breathing) or while in other positions (supine). Therefore, the authors concluded that resting, speech and exercise respiration result from different neural pathways and the dystonia can affect one pathway more than the others. Interestingly, these authors also briefly reported on previous research that found this same population to have irregular measures of rapid shallow breathing (Braun et al., 1995).

Inductance plethysmography has also been used to evaluate the differences in breathing patterns in healthy children while in the sitting, standing and supine positions (Mayer, Clayton, Jawad, McDonough & Allen, 2003). The thoracic/abdominal coordination of children was examined in each of the three positions. The researchers found significant differences in the coordination between the positions. For example, nearly synchronous movements between the subsystems were found in the sitting position, while asynchronous movements were used in the supine position. In addition, the researchers examined the feasibility and, what the authors termed, success of using this instrument with this young population. Feasibility was defined as a willingness to participate in the study, while success was defined as the ability for the participants to perform the study's procedure. Out of the 50 participants, 49 were willing to participate (feasibility) and 42 had success in performing the desired tasks. Therefore, the researchers felt the instrument was both feasible and successful for this population (Mayer et al., 2003). These results can be considered universal to the general public because, if the instrument is non-threatening and easy to use for children, adults should have no problem with it.

In another study, Iwarsson (2001) used inductive plethysmography to examine the positioning of the larynx during different abdominal postures while breathing. She postulated that abdominal wall expansion would be accompanied by tracheal pull resulting in a lowered laryngeal position. Subjects were asked to alter their abdominal expansion by either keeping it pushed out or pulled in during speech tasks. Plethysmography was used as a visual feedback method for the subjects, as they were asked to begin speaking when they reached about 70% vital capacity. Results of the study indicated that clear differences in the vertical laryngeal positioning occurred during the two abdominal speaking positions. A higher laryngeal position resulted when the abdomen was pushed out. These results indicated that the author's original hypothesis was not supported.

These study descriptions have provided examples of the research use of inductance plethysmography. It has been used to measure various breathing parameters and evidence validating its use in research settings has been provided. Therefore, researchers can use this instrument to determine the patterns of breathing in individuals with a disordered larynx, the results of which could possess significant clinical value

## Breathing with a Disordered Larynx

Variations in speech breathing have been reported in individuals with disordered larynges (Bunton, 2005; Plant & Hillel, 1998; Makiyama, Kida & Sawashima, 1998; Saarinen, Rihkanen, Malmberg, Pekkanen & Sovijari, 2001; Sapienza et al., 1997; Schaeffer et al., 2002; Vertigan, Gibson, Theodoros, Winkworth, Borgas & Reid, 2006). The phonatory and respiratory systems must work in concert to yield the precise framework from which to produce normal speech. If one system is not functioning appropriately, the other system may begin to function differently. Some authors believe an individual alters his/her respiratory behavior in order to compensate for the disordered larynx (Sapienza et al., 1997; Vertigan et al., 2006). These investigators have described that individuals with voice disorders tend to produce deep inhalations and initiate speech at different lung volumes compared to controls. These behaviors were attributed to an attempt to "overcome respiratory difficulty, compensate for air loss at the glottal level and regulate subglottal pressure during phonation" (Vertigan et al., 2006, p. 648). In addition, increased or decreased air flow rates, differing end inspiratory or expiratory lung volumes, changes in subglottal pressure and paradoxical movements have been reported in persons with disordered larynges (Bunton, 2005; Makiyama et al., 1998; Plant & Hillel, 1998; Saarinen et al., 2001; Sapienza et al. 1997; Schaeffer et al., 2002; Vertigan et al., 2006).

### *Airflow*

The most apparent change observed in the speech production of those with disordered larynges is from the effects of altered airway resistance at the level of the glottis. Depending on the type of laryngeal disorder, glottal resistance can be increased or decreased. For example, vocal nodules will prevent the vocal folds from fully closing. There will be small spaces around the nodule area and air will escape through these spaces during phonation (Sapienza et al., 1997). Therefore, a subsequent decrease in laryngeal resistance with an increase in airflow would be expected. Increased airflow rates were found when researchers examined the respiratory behaviors in women with vocal nodules. Further, the production of each spoken syllable resulted in a larger expulsion of air when compared to controls. The conclusions of this study highlight the tendency for airflow to be altered when pathology is located within the larynx.

Makiyama et al. (1998) examined expiratory lung pressure and airflow rates during a sustained vowel task in individuals with Reinke’s edema and patients with recurrent nerve paralysis. Individuals were required to sustain a vowel at a comfortable level and then increase and decrease the intensity without altering the pitch. Results of the study indicated that all participants increased subglottal pressure to increase intensity, resulting in elevated airflow rates. When compared across groups, however, differences in the degree of increased pressure and airflow were found. For example, the group with paralysis was found to have substantially increased airflow. The authors hypothesized that this group increased airflow to increase vocal intensity because they could not increase laryngeal tension.

Saarinen et al. (2001) studied airflow in individuals with vocal fold paralysis. Flow-volume spirometry and body-plethysmography were used to examine respiratory patterns in quiet and forced breathing. Specifically, forced inspiratory and expiratory flow was lower than that of controls. These findings would suggest that because the paralyzed vocal fold created an obstruction at the level of the larynx, airflow is hindered. In this case, obstruction at the level of the larynx can inhibit force respiration.

### *Lung Volumes*

In addition to altered airflow, there is evidence showing there are differences in lung volumes during speech when comparing individuals with laryngeal pathology to controls. Sapienza et al. (1997) hypothesized that individuals compensate for the increased airflow related to the laryngeal pathology by initiating speech production at high lung volumes. These researchers found the women with vocal nodules expended larger volumes of air per syllable and utterance during connected speech when compared to controls. Because airflow was increased with each syllable and a larger volume of air was expended during the speaking tasks, the researchers postulated that larger volumes of air are needed to maintain the necessary subglottal pressure for phonation.

Bunton (2005) examined lung volume use in individuals with Parkinson’s disease (PD). Lung volumes at the initiation and termination of a conversational speech task were measured. Findings from this study indicated many differences in breathing parameters between the PD and control groups. The participants in the PD group produced fewer syllables per breath group and evidenced a shorter duration of expiratory time during speech. In addition, this group initiated and terminated speech at lower lung volumes. This was attributed to an increased effort during speaking. These results are in contrast to Sapienza et al. (1997), who hypothesized increased initiating lung volumes to maintain subglottal pressure. The differences may lay in the different populations examined. While Bunton (2005) examined individuals with PD (a disorder interfering with neural innervations), Sapienza et al. (1997) examined women with vocal nodules (a laryngeal lesion). Hence, the nature of the laryngeal pathology may affect breathing patterns.

In another study of individuals with non-neurological related laryngeal pathology, Schaeffer et al. (2002) examined the venitilatory behaviors of ten women with abuse-related dysphonia. Specifically, participants were asked to read two sets of paragraphs: a ten syllable-per-sentence paragraph and a 60 syllable-per-sentence paragraph. Those with dysphonia had lower end-expiratory lung volumes while speaking than controls. This finding, exacerbated in the longer speaking task, was attributed possibly to the use of the grammatical periods as linguistic markers within the text indicating acceptable places to replenish the air supply. Therefore, the dysphonic group increased the demands on the respiratory system by producing speech well below the resting end expiratory level in order to maintain continuity within the reading text. The control group, however, utilized more efficient breathing patterns by terminating speech at or above this level.

Data has confirmed that individuals will change lung volumes at the initiation of speech (Bunton, 2005). In addition, reliable data confirms lung volumes at the end of speech are also altered (Bunton, 2005; Schaeffer et al., 2002). Interestingly, all of the above mentioned studies reported that their subjects terminated speech at lower lung volumes compared to controls (Bunton, 2005; Saarinen et al., 2001; Sapienza et al., 1997; Schaeffer et al., 2002). Speaking at lower lung volumes may create an unnecessary need to increase muscle effort in order to maintain proper subglottal pressure. This increased muscular effort may, in turn, create tension within the respiratory mechanism (Saarinen et al., 2001). The tension may further exacerbate changes in respiratory behaviors.

### *Subglottal Pressure*

As mentioned previously, proper subglottal pressure must be maintained in order to phonate. Not surprisingly, researchers have found variations in subglottal pressure in populations who exhibit voice disorders (Schaeffer et al., 2002). Jiang, O’Mara, Chen, Stern, Vlagos & Hanson (1999) examined the aerodynamics of 24 individuals with PD. They found significantly greater subglottal pressures in this group when compared to the control group. They attributed this finding to increased laryngeal resistance during phonation. It was concluded that the participants with PD used an increased subglottic pressure (possibly with increased expiratory effort) to compensate for the laryngeal resistance because of the presence of a neurological laryngeal pathology.

Makiyama et al. (1998) examined the expiratory lung pressures before and after increasing vocal intensity in three groups of participants: individuals with Reinke’s edema, individuals with recurrent laryngeal nerve paralysis and a control group. Results revealed increased subglottal pressure and airflow in all groups when increasing vocal intensity. Those with Reinke’s edema exhibited extremely elevated expiratory lung pressures that it differentiated this group from the other two. This finding was attributed to increasing expiratory effort in order to overcome the increased laryngeal resistance because of increased vocal fold mass.  Those with paralysis exhibited elevated expiratory lung pressures in both the comfortable and increased vocal intensity task, however to a lesser degree than the controls or those with edema.  In paralysis, there would be less physical resistance because the laryngeal muscles are paralyzed, and therefore, cannot resist airflow or maintain increased pressure.  Not surprisingly, this group experienced extremely elevated airflow rates that distinguished them as a group.

### *Physical Respiratory Movements*

The research described above has demonstrated that laryngeal disorders may affect respiration in a variety of ways, such as altered airflow, lung volumes and subglottal pressure.  In addition, evidence has been provided in the literature suggesting that laryngeal disorders can affect the physical framework of respiration in regards to rib cage and abdominal movements.  For example, Vertigan et al. (2006) briefly commented on previous research that individuals with voice disorders exhibit paradoxical chest wall movements while speaking in their discussion of the pulmonary functioning of individuals with a voice disorder.  Research conducted by Schaeffer et al. (2002) support this claim.  In this latter study, the researchers used inductive plethysmography in order to evaluate the movements of the respiratory system.  They found that the subjects with dysphonia exhibited a greater frequency of abnormal expiratory abdominal movements during speech, suggesting that the physiological process of respiration is altered in these participants.

In her study of lung volume use in individuals with Parkinson’s disease, Bunton (2005) observed greater effort during the speaking tasks.  This effort was attributed to the increased abdominal activity needed to overcome a rigid rib cage that may occur in Parkinson’s disease. This increased abdominal contribution may have been used to maintain the subglottal pressure needed while speaking at low lung volumes. In other words, because the rib cage was less flexible, the abdomen took on a larger role in the respiratory process, thereby allowing the individuals to maintain and control the expiring air for speech production purposes.

The information provided above has demonstrated that laryngeal disorders have various influences on measurements of respiration related to airflow, volumes, pressures and the physical movements. For the purposes of the present study, one specific disorder of the larynx and its influence on respiration is examined.

## Spasmodic Dysphonia

The spasmodic dysphonias (SD) are one set of phonatory disorders that are characterized by voice breaks due to involuntary contractions of the adductor (closing) or abductor (opening) muscles of the vocal folds. According to the National Spasmodic Dysphonia Association (NSDA, 2006), there are approximately 50,000 people diagnosed with SD in North America. This number is thought to be an underestimate because the disorder can often be misdiagnosed as Muscle Tension Dysphonia (MTD). MTD is a form of dysphonia due to excess muscle tension within the larynx. MTD and SD share similar perceptual characteristics, such as hoarseness and limited pitch and loudness range, however SD has more of a strained/strangled vocal quality (Sapienza, Walton, & Murry, 2000).

The spasmodic dysphonias can be classified into three groups: adductor spasmodic dysphonia (ADSD), abductor spasmodic dysphonia (ABSD), and mixed spasmodic dysphonia. For the purposes of the present study, this paper will focus on the adductor type. As the name implies, ADSD involves spasms of the adductor laryngeal muscles. These muscles are responsible for closing the vocal folds. Adduction of the folds occurs at each muscular contraction, resulting in excessive medial compression of the folds (Cannito & Woodson, 2000). These spasms severely disrupt the normal closing and opening of the vocal folds. The result is a strained/strangled vocal quality that sounds characteristically similar to glottal fry (Cannito & Woodson, 2000).

The perceptual characteristics of ADSD are often very similar to other voice disorders. However, differentiating the disorders is important in terms of underlying origin, disease progress and treatment options (Lundy, Roy, Xue, Casinao, & Jassir, 2004). Sapienza et al. (2000) performed an acoustical analysis on individuals with ADSD and MTD with hopes of developing a framework to differentially diagnose ADSD from MTD. The researchers specifically examined aperiodicity, phonatory breaks, and frequency shifts. They found that those with ADSD produced significantly more phonatory breaks, aperiodic segments and frequency shifts during sustained vowel tasks (Sapienza et al., 2000). Most notable was the presence of phonatory breaks in those with ADSD, while there were no instances of breaks in voicing in the MTD group. The cessation of phonation occurs when vocal folds are tightly compressed. Continuous phonation is not possible because the involuntary muscular contractions prevent phonation due to the tight medialization. The researchers therefore claimed, that determining the presence of phonatory breaks could provide useful information when diagnosing ADSD. Overall, acoustical analysis, although useful, cannot alone provide a basis for differential diagnosis.

Researchers have attempted to find other non-invasive means for differentially diagnosing ADSD. For example, Lundy et al. (2004) examined speech production parameters by means of a motor speech profile analysis in individuals with ADSD, amyotrophic lateral sclerosis (ALS), and tremor. These three disorders were chosen for study because they shared similar perceptual features (strained, strangled and tremulous vocal quality) but had different etiological origins. The researchers concluded that although the voice symptoms of these disorders perceptually sounded similar (i.e. strangled), differences did exist. First, they found the individuals with ADSD to have a speaking fundamental frequency closer to that of normative data when compared to the other two groups. Also, those with ADSD performed diadochokinetic tasks faster than those with ALS or Tremor; nevertheless, all three groups had a slow connected speech rate (Lundy et al., 2004). On the other hand, pitch variability tasks did not show a statistically different range between the groups, and should not be used in differentially diagnosing these disorders.

### *Respiration in Adductor Spasmodic Dysphonia*

Researchers have described the necessity for the respiratory system to compensate for laryngeal tension caused by the spasms in SD (Cannito & Woodson, 2000; Woodson, Zwirner, Murry & Swenson, 1992). Woodson et al. (1992) reported a decreased phonatory airflow rate with increased subglottal pressure in this population. Presumably, the increased subglottal pressure is needed to overpower the medial compression while flow is impeded due to the spasms.

In another study, Plant & Hillel (1998) examined subglottal pressure and intraoral air pressure during continuous syllable production in seven individuals with ADSD.

Pressure detecting devices were inserted in the trachea using needle electrodes and into the oral cavity via a facemask. This allowed for the comparison of subglottic and oral pressures. They found a decrease in airflow with an increase in subglottal air pressure that, at times, surpassed the pressure measured intraorally. Therefore, these participants, with an increased expiratory lung pressure, produced decreased airflow. These findings seemed to indicate that laryngeal spasms affected both airflow and air pressure. Specifically, the individuals with ADSD were compensating for the spasms by increasing subglottal pressure, while the spasms were simultaneously hindering airflow. Airflow was reduced because the spasms are constantly creating an obstruction within the larynx.

Another aerodynamic study of ADSD was completed by Higgins, Chait & Schulte (1999). These researchers examined phonatory airflow in this population. Specifically, the authors measured mean phonatory airflow, the variation of airflow (breath to breath changes in airflow) and airflow perturbations (an increase and then decrease of airflow of 75ml/s) via an intraoral air pressure sensing device and a pneumotactograph. Those with ADSD exhibited greater airflow variability with overall lower phonatory airflow. Further, this group consistently demonstrated more airflow perturbations when compared to a control group and a group diagnosed with MTD. The authors contributed the large airflow variability to both glottal deficiency and to changes in respiratory driving pressures. In other words, when individuals with ADSD experienced the spasms, they increased respiratory pressure to overcome the spasm in order to continue to phonate.

The previous studies have suggested that individuals with ADSD are likely to experienced increased subglottal pressure with decreased airflow rates. It is important to know if these aerodynamic parameters are return to normal in patients with ADSD after

Botox injections. Therefore, various studies have focused on the phonatory aerodynamics of individuals post-botox injection. Adams, Durkin, Irish, Wong and Hunt (1996) completed a study in which the aerodynamics of individuals with ADSD were compared to a control group. Individuals in the ADSD group were measured three times: prior to injection, two to four weeks post-injection, and eight to ten weeks post-injection; while data was obtained from the control group two times with two weeks separating the measurements. The speaking task consisted of repeated /pa/ syllables and the participants used a face mask with an intraoral pressure sensing device to measure airflow and pressure. The results of the study indicated significant decreases in laryngeal resistance and variability of airflow with an increase in average airflow post-injection. It seems, therefore, the injections inhibited the spasms, which decreased the glottal resistance. With lowered resistance, airflow naturally increased and airflow variability decreased. Therefore, the participants with ADSD experienced near normal values for these measures after treatment in the form of Botox injection.

Other studies of the aerodynamics of respiration post-Botox injection have also found increased airflow rates. For example, an increase in airflow during sustained vowels was found in a study by Cantarella, Berusconi, Maraschi, Ghio, and Barbieri, (2006). The post-injection airflow values were significantly different from pre-injection values, but were not significantly different when compared to controls. In addition, airflow variability was measured and post-injection airflow values were significantly more stable compared to pre-injection levels. Interestingly, although these values indicated a more stable airflow after Botox than pre-injection, patients with ADSD still evidenced a higher level of variability in airflow than controls.

Similarly, increased airflow rates post-injection were found in a study completed by Woo, Colton, Casper and Brewer (1992). This study specifically examined airflow pre- and post-Botox injection and in unilateral nerve block (another form of treatment for ADSD). The researchers found that those who were injected with Botox improved their airflow rates to values within the normal range, while those who underwent nerve block had post-treatment airflow rates well above the normal range (Woo et al., 1992). The authors concluded that Botox injections allowed for the participants to phonate with a more normal airflow rate than those who chose nerve block (Woo et al., 1992).

## Statement of the Problem

Evidence has been presented that suggests laryngeal movements not only relate to respiratory events, but also that respiratory behaviors may be altered in those with disordered larynges. This interdependent relationship demonstrates how the two (respiratory and phonatory) systems rely on each other and explains how deviations of normal respiratory functioning may occur when the phonatory system is defective. The studies related to ADSD that are presented above basically inspected respiration related to measurements of airflow and neglected some of the other respiratory parameters. What is lacking in these studies is information regarding the respiratory behaviors involving lung volumes, respiratory times and the physical movements related to respiration. Given the evidence base, it seems intuitive that these respiratory parameters would also be altered. Research needs to be conducted on individuals with ADSD that investigates these specific measures of respiration. Therefore, the present study focuses on respiration and ADSD. Specifically, are respiratory patterns altered in individuals with ADSD?

As discussed above, the Respitrace instrumentation has been proven as a valid and sensitive instrument to measure various breathing parameters. The Respitrace generates several different measures of breathing. For the purposes of this investigation, measures of volume, timing, thoracic displacement and respiratory efficiency were considered. The following questions were asked:

1. Do individuals with ADSD differ from age- and gender-matched controls on measures of respiratory volume, timing, thoracic displacement and efficiency?
2. Do differences in measures of respiratory volume, timing, thoracic displacement and efficiency vary by speaking task or gender?

# Methods

In order to produce voice, a balance must be maintained between the respiratory and phonatory systems. When one of these systems becomes dysfunctional, the other system will no longer perform normally. Many researchers believe the changes at the respiratory level are the direct result of a need to compensate for the disruption at the laryngeal level (Sapienza et al., 1997; Vertigan et al., 2006). Individuals with ADSD may experience reduced phonatory airflow rates and increased subglottal pressure (Cannito & Woodson, 2000). Previous research, however, has only focused on these parameters. Yet to be studied are other parameters of breathing that may broaden our understanding of the level of compensation by the respiratory system. Therefore, this study was designed to examine parameters involving respiratory volume, timing, thoracic displacement and efficiency in the speech of individuals with ADSD.

## *Participants*

Twenty-five adults were recruited from the Ear, Nose and Throat (ENT) Clinic at a medical university in southwest Florida. These individuals were at the clinic for their regularly scheduled Botox injection. They were asked to participate in this project prior to receiving their injections.

Individuals were considered eligible for the adductor spasmodic dysphonia (ADSD) group if they had a medical diagnosis of ADSD. Individuals with a co-existing neurological or neuromotor disorder or an inadequate reading ability were excluded from this study. Participants self-reported a co-existing neurological disorder. Reading ability was judged during the oral reading tasks and one person was excluded from the study due to poor oral reading skills. This participant's reading ability was judged to be nonfluent because that participant demonstrated many false starts and long pauses while reading aloud.

Of the 25 participants, fifteen were ultimately included in the ADSD group; nine women and six men. The mean age for the females was 60.77 years (*s.d.* = 12.96 years) and the mean age for the males was 50.33 years (*s.d.* = 11.39 years). The data collected from the remaining ten participants were not included because of computer corruption of data files, researcher error when conducting the study, and poor quality speech samples.

Sixteen age- and gender-matched individuals agreed to participate as the matched control group. These participants were members of the community, faculty from the Communication Sciences and Disorders department or acquaintances of the researchers. Individuals were asked to participate in the study if they reported being a non-smoker and were free of a neurological/neuromotor disorder or respiratory disease. Data from fifteen of the individuals were included: nine women and six men. The mean age for the females was 56.33 years (*s.d.* = 7.62 years) and the mean age for the males was 53.5 years (*s.d.* = 11.39 years). Data collected from the remaining individual was excluded because of poor quality of the speech sample and Respitrace band slippage, which resulted in questionable Respitrace waveforms.

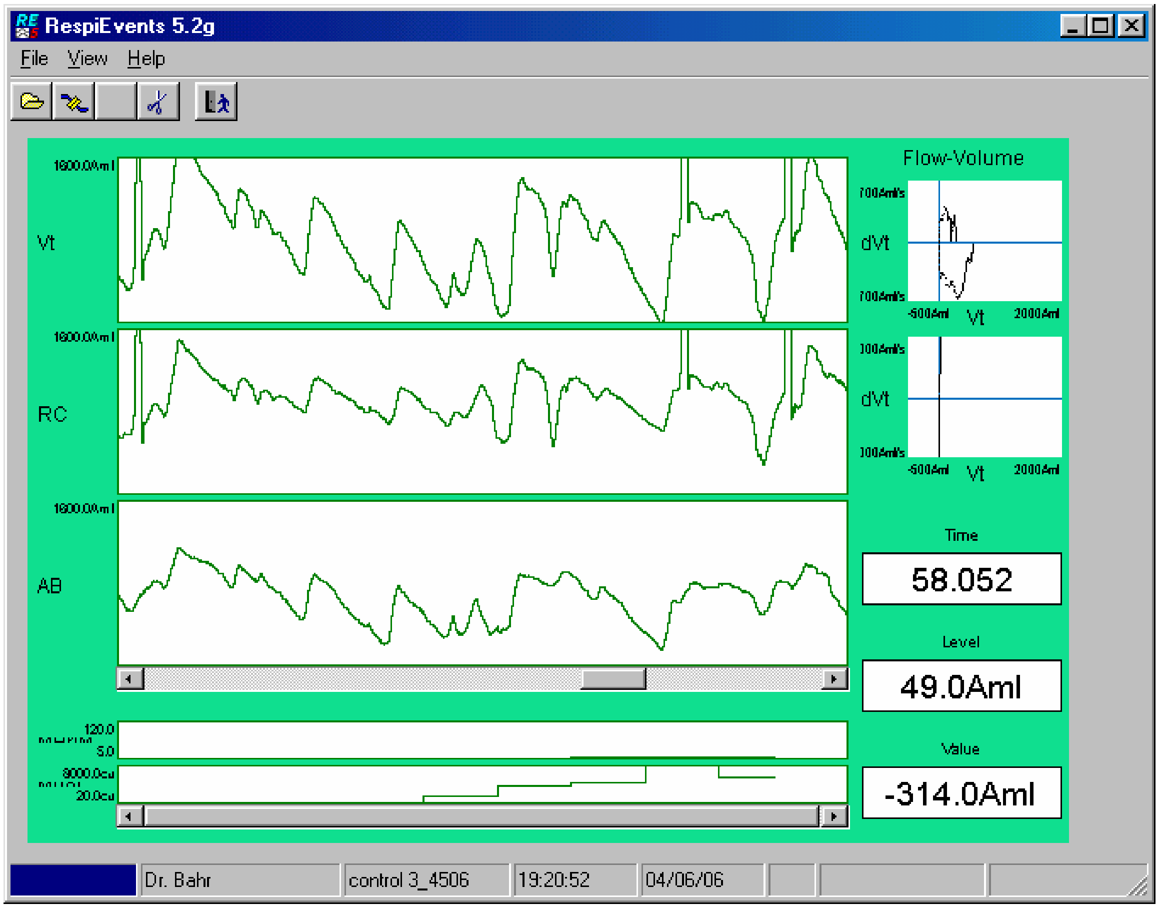
### *Materials*

Respitrace and RespiEvents (Nims, 2002) were used to quantitatively measure the breathing process. Specifically, the Respitrace bands act as an inductive plethysmograph.

Plethysmography is a method of determining air pressure, volume and flow by calculating changes in air volumes while breathing.  The Respitrace, when compared to spirometry or other pneumotachography, has been shown to be accurate within 10% of the estimated changes while breathing (Nims, 2002).

Respitrace requires the use of a vest that is wrapped around an individual’s rib cage and abdomen.  This vest consists of two elastic bands with embedded coiled wires. These wires calculate and quantify any thoracic movement by forming a stretchable loop around the body so that the wires change size with the rib cage and abdominal excursions.  These changes are quantified and a sinusoidal waveform that represents inhalation and exhalation is produced within RespiEvents.  Figure 1 is an example of a waveform obtained during the study.  The top display represents the tidal volume, the middle display represents the rib cage trace and the bottom display is the abdomen trace. These tracings were extracted from a control participant during a speaking task.

Figure 1. An example of a waveform produced by a control participant as viewed via the RespiEvents software.



Time
58.052

Level
49.0Aml

Value
-314.0Aml

Dr. Bahr
control 3_4506
19:20:52
04/06/06

An initial calibration period of five minutes was completed for each participant. This calibration period allowed for Respitrace to track typical breathing patterns for each individual and to calibrate the equipment for experimental use. After this calibration period, the data obtained from Respitrace were converted to arbitrary volume units (Aml) by RespiEvents.

Participants were asked to complete four tasks in a random order: two readings and two conversational tasks. The reading tasks involved two readings of the first paragraph of the *Rainbow Passage* (Fairbanks, 1960), while the conversational tasks consisted of two separate tasks. The first task involved a description of the “Cookie Theft” picture from the *Boston Diagnostic Aphasia Examination*, 3rd Edition (Goodglass, Kaplan, & Barresi, 2000). The second conversational task varied by group. The ADSD group answered the question, “Tell me about your experiences being diagnosed with spasmodic dysphonia”. Individuals in the control group were instructed to speak about a topic of interest for approximately one minute. These tasks were designed to elicit conversational speaking patterns.

### *Procedures*

All participants were briefed on the purpose and procedures of the study and asked if they were willing to participate. If they agreed, an informed consent was signed and the study began. Each individual was carefully fitted with the Respitrace bands. One band was wrapped around the participant’s rib cage and the other around his/her abdomen. The bands were securely attached to prevent band slippage. To ensure a good fit, Velcro was used to attach the two ends of the bands together and any excess band was tightly pinched together, folded over, and secured with duct tape. Wires were then connected to the bands and held in place via a snap. These wires then lead to the Resptrace device, which was also connected to a computer. RespiEvents converted the traces into waveforms to be further processed into measures of various aspects of breathing.

Table 1 illustrates the presentation order of speaking tasks utilized during this experiment. For example, participant 1 was asked to read the paragraph, describe the “Cookie Theft” picture, reread the paragraph and finally engage in 1.5 minutes of dialogue. The next participant was asked to complete the same tasks, however in a different order: respond to the question, read the paragraph, describe the picture and finally reread the paragraph.

Table 1. A table representing the randomization of speaking tasks presented to participants.

| | Participant 1 | Participant 2 | Participant 3 | Participant 4 |
|---|---|---|---|---|
| Order 1 | Paragraph Rdg | Response to ? | Paragraph Rdg | Picture Descrip |
| Order 2 | Picture Descrip | Paragraph Rdg | Response to ? | Paragraph Rdg |
| Order 3 | Paragraph Rdg | Picture Descrip | Paragraph Rdg | Response to ? |
| Order 4 | Response to ? | Paragraph Rdg | Picture Descrip | Paragraph Rdg |

At the start and finish of each task, the researcher pulled either the rib cage or abdominal band, which produced a notable spike within the computer waveform. This motion allowed for the easy identification of the beginning and end of each speaking task within the waveform. To verify that the correct portion of data was being analyzed, the duration between spikes was compared to the speaking duration obtained from audio recordings.

The participants were audio recorded using an Optimus voice activated full auto-stop cassette recorder (model number CTR-117 14-1123). Recordings were played back and the duration of the speech sample during each task, in order to match recording time with the waveforms recorded within RespiEvents.

All data was transferred from RespiEvents to an Excel file via an ASCII cut. This process converted the data into a readable form, by representing all data as numerical values on a breath-by-breath basis. These values represented breathing parameters in terms of volumes, times, derivatives, and rib cage and abdominal movements. A spreadsheet was created, to organize and store the data.

## *Measured Breathing Parameters*

RespiEvents (Nims, 2002) allows for the acquisition and analysis of many breathing parameters, such as measures of tidal flow-volume loops, breath and heart rate parameters and Electrocardiogram (ECG) waveforms. For the purposes of the present study, fourteen breathing parameters were analyzed and compared across groups and tasks. Specifically, three volume measures were analyzed: inspiratory and expiratory amplitude (ViVol and VeVol, respectively) and the minute ventilation (Vent). Six timing measures were recorded: breaths per minute (Br/M), inspiratory time (Ti), expiratory time (Te), total breath time (Tt), a fractional inspiratory time (Ti/Tt) and the time to reach expiratory flow (PefTTe). Two measures that related specifically to thoracic displacement were analyzed: the percentage of rib cage contribution (%RC) and a Labored Breathing Index (LBI). And finally, three measures of respiratory efficiency were recorded: a rapid shallow breathing index (F/Vt), peak inspiratory flow (PifVt) and a measure of respiratory muscular efficiency and breathlessness (VePif). More detailed definitions follow.

### *Volume measures*

A total of three measurements relating to volume were chosen for this study. Previous evidence has shown that individuals with disordered larynges utilize different volumes of air during speaking tasks (Bunton, 2005; Saarinen et al., 2001; Sapienza et al., 1997; Schaeffer et al., 2002). Therefore, the present investigators wanted to examine measures of respiratory volume in order to determine if the obstruction at the level of the larynx impacted that amount of air inhaled or exhaled. It was thought that increased lung volumes would be needed in order to overcome this obstruction. The measurements related to volume are as follows:

*Inspiratory volume (ViVol).* This measurement represents the inspiratory amplitude of the tidal volume. The tidal volume is the volume of air that is inhaled and exhaled on a single breath. This parameter, therefore, represents the volume of air inhaled during each breath.

*Expiratory volume (VeVol).* VeVol represents expiratory amplitude of the tidal volume, or the volume of air that is exhaled on a single breath. During quiet breathing, this measurement should equal the inspiratory amplitude. RespiEvents begins to measure this when the inspiratory amplitude peak for each breath is reached and the thoracic volume begins to decrease.

*Ventilation (Vent).* Ventilation is calculated by multiplying the ViVol by breaths per minute. This provides an assumed minute ventilation rate that represents respiratory muscle efficiency.

*Timing measures*

A total of six measurements relating to timing were chosen for this study. Previous research has not specifically targeted the respiratory parameters related to timing. Therefore, measures of respiratory time were analyzed in order to determine if the obstruction at the level of the larynx impacted the duration of breathing patterns. It was thought that because this population experiences insufficient glottal pressure, the timing of respiratory patterns may be changed or adjusted to create an increased subglottal pressure needed to overcome this obstruction.  The measurements related to volume are as follows:

*Breaths per minute (Br/M).*  Breaths per minute is the respiratory rate calculated breath-by breath.  In other words, Br/M represents how many breaths would be taken if the individual maintained the respiratory rate seen at each breath.  For example, if one breath lasted 10 seconds then the Br/M would be approximately 6, for that particular breath.  However, if the next breath lasted 6 seconds, then the Br/M would be 10. Intuitively, quiet breathing results in a more stable and regular respiratory rate and ultimately a lower Br/M value, whereas, during activity (or for our purposes, speech breathing) the rate at which a breath is taken will be more likely to vary from breath to breath.

*Inspiratory time (Ti).*  This is the time in seconds from the initiation of a breath to its peak inspiratory volume.

*Expiratory time (Te).*  Te measures the time in seconds from the peak inspiratory volume to the end expiratory volume.

*Total breath time (Tt).*  Tt is the duration in seconds from the initiation of a breath to the completion of that breath.

*Fractional inspiratory time (Ti/Tt).*  In this instance, inspiratory time (Ti) is divided by the total breath time (Tt) and given on a breath-by-breath basis.

*Time to reach peak expiratory flow (PefTTe).*  This value is presented as a percentage of expiratory time and represents the time to reach peak expiratory flow.

### *Thoracic displacement*

A total of two measurements relating to the displacement of the rib cage and abdomen were chosen for this study. A study by Schaeffer et al. (2002) examined the physical displacement of the respiratory structures during speech breathing in individuals with dysphonia. They found a greater frequency of abnormal expiratory abdominal movements in this population. Therefore, measures of thoracic displacement were analyzed in order to determine if the obstruction at the level of the larynx impacted the coordination or contribution of the rib cage and abdominal movements. The measurements related to thoracic displacement are as follows:

*Percentage of rib cage contribution (%RC).* This measurement calculates the contribution of rib cage movement to the generation of tidal volume. It is obtained by dividing the rib cage amplitude by the tidal volume at the peak of inspiratory volume. Its value is given as a percentage on a breath-by-breath basis. In normal adults during quiet breathing, the rib cage involvement tends to exceed abdominal involvement and a typical percentage of rib cage involvement is 60% (Nims, 2002).

*Labored breathing index (LBI).* The labored breathing index measures thoracic-abdominal coordination by comparing the power generated at the rib cage and abdominal level to the actual amount of power delivered (in the tidal volume). Perfect coordination would produce a ratio of 1.0. A mildly increased LBI would produce a ratio of 1.3-2.0 and extremely high LBI values are above 3.0 (Nims, 2002). A high LBI value could possibly indicate muscular dysfunction or pulmonary obstruction.

### *Respiratory Efficiency*

A total of three measurements relating to the respiratory efficiency were chosen for this study. These parameters are obtained through a comparison of the tidal volume to one or more measures of time, volume or movement. Little to no research has specifically examines these parameters in relation to speech breathing in patients with ADSD**.** Therefore, these measures of respiratory efficiency were analyzed in order to determine if the obstruction at the level of the larynx impacted respiratory functioning. The measurements related to respiratory efficiency are as follows:

*Rapid shallow breathing index (F/Vt).* F/Vt is computed by dividing Br/M by the tidal volume, giving an indication of the respiratory frequency.

*Peak inspiratory flow (PifVt).* This derivative reflects respiratory drive. It is the peak inspiratory flow derived from the tidal volume. The higher the value, the greater the respiratory drive.

*Respiratory efficiency and breathlessness (VePif).* This parameter reflects respiratory muscular efficiency and breathlessness. It is calculated by dividing the minute ventilation by the peak inspiratory flow of the tidal volume. Minute ventilation is the volume of air inhaled and exhaled in one minute. VePif compares the respiratory drive to the respiratory output (ventilation). Respiratory drive has shown to be greater in those with respiratory disease than in controls (Nims, 2002).

After much deliberation, these parameters were chosen because of the potential to show the changes in respiratory patterns. As mentioned in the literature review, measures of lung volume and physical displacement are altered in individuals with disordered larynges (Bunton, 2005; Sapienza et al., 1997; Schaeffer et al., 2002; Vertigan et al., 2006). Specifically, evidence has shown that individuals may initiate speech at lower or higher lung volumes and terminate speech at lower lung volumes. In addition, aberrant respiratory movements may have been evident in this population. Therefore, these two categories, in addition to respiratory timing and efficiency, were included in the present study to determine if individuals with ADSD utilize different respiratory behaviors when compared to a control group.

### *Data reduction*

Once RespiEvents processed the information coming from the Respitrace vest, the data was converted to an Excel file via an ASCII cut. This process converts the waveform data into a readable form, by representing all data as numerical values. More specifically, the data was placed into an Excel spreadsheet (Microsoft, 1998), in which the data was organized and stored. The cuts were performed on a breath-by-breath basis as the guide for the rows of the spreadsheet and each breathing parameter served as a column name.

The breathing parameters described above were extracted from the RespiEvents spreadsheet. The values obtained during each task (given in a breath by breath fashion) were averaged together and the standard deviation was computed for each participant. This data was then combined to get an average for the reading tasks and an average for the conversation tasks for each participant. The averages for each breathing parameter within each task were used to determine if the differences seen between groups, gender and task were statistically significant.

### *Reliability*

The data obtained from two participants from each group were randomly selected to determine the intra-judge reliability. The goal was to perform the same analysis used during the study to determine the beginning and end breaths for each task resulting in the determination of which breath groups were used during the speaking tasks. This process was completed through review of the audiotapes, analysis of the duration of each speaking task and the waveforms. The vertical spike in the waveform, which correlates to the quick pull of the bands during the tasks, gave a general marking of the placement of the tasks. The actual determining of the speaking portion was completed by comparing the waveform to the duration of the speaking tasks. The information from the audiotape helped to establish if the sample contained initial pauses, large inhalations (without a speaking component), coughing, throat clearing, etc. If this were true, then the initial breaths were excluded from the analysis. For example, one participant began a reading passage by inhaling a large volume and quickly exhaling while saying “alright.” The actual reading began with the next inhalation. This was excluded from the study because the respiratory pattern did not reflect the rest of the sample. Because each participant engaged in four speaking tasks, and four participant’s data were analyzed, a total of 16 speaking tasks were re-determined. Out of the 16 tasks, 14 beginning and end breaths were matched correctly. The remaining two analyses were off +/- 1 breath. These had the beginning breath off by +/- 1 breath with correctly matching the end breath. In total, these four participants contributed a total of 148 breaths for the study’s analysis. During reliability testing, 146 breaths matched correctly. This means that when using the methods described above, 98.6% of the breaths would match correctly.

One factor seemed to have influenced why the reliability testing did not match exactly. The discrepancy was attributed to small errors in judgment of which wave within the waveform indicated the initial speaking breath. This was the case because, often, the waveform was a shaky line with breaths squeezed closely together. When this was the case, the next breath or set of breaths that were obviously part of the speaking task was used as the initial breath. During reliability testing, the same judgment calls were attempted and judged differently. Nevertheless, this occurred infrequently and reliability was considered to be very good.

### *Statistical Analysis*

Each breathing parameter was analyzed using a multivariate analysis of variance (MANOVA). All dependent variables (i.e. the number measures of breathing) were compared across the three independent variables: group (ADSD vs. control), gender (male vs. female) and task (reading vs. conversation). When analyses yielded an interaction between the three independent variables, post hoc analysis testing was completed using Tukey A procedures. Effect sizes were calculated as appropriate.

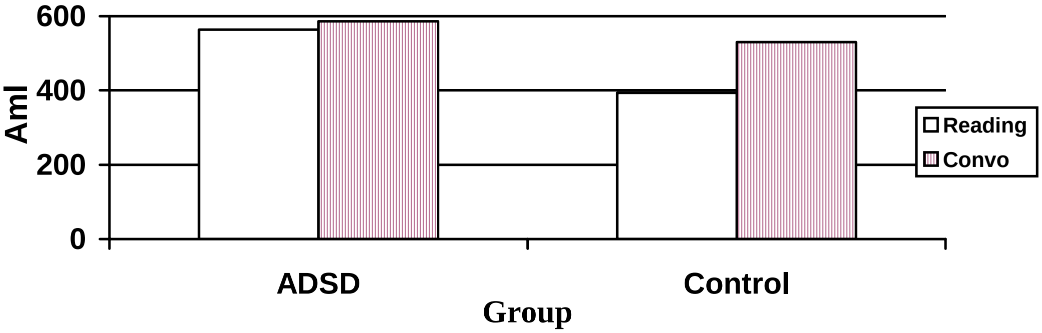
# Results

The purpose of this study was to collect data on various breathing parameters while participants were engaged in two speaking tasks. In order to achieve this, participants wore a vest connected to computer software that computed breathing parameters via inductance plethysmography. The resulting breathing parameters were analyzed across groups (ADSD vs. control), gender and speaking tasks. The various breathing parameters were chosen due to suspicion that the obstruction at the glottal level would alter the selected parameters. All parameters were classified and grouped into one of four categories: volume, timing, thoracic displacement and respiratory efficiency. Results are presented below according to each category.

## *Volume*

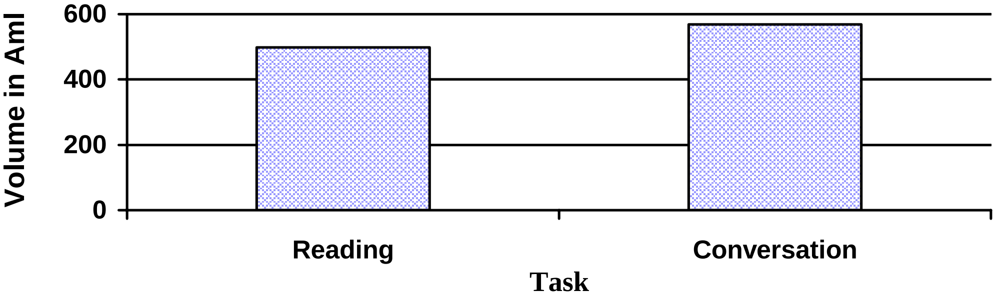
The first set of MANOVAs were performed for the volume measures, inspiratory volume (ViVol), expiratory volume (VeVol) and minute ventilation (Vent). The first analysis considered inspiratory volume (ViVol). Results revealed a significant interaction between task and group, $F(1,26) = 4.212$, $p = .05$, $\eta_p^2 = .139$. Post hoc testing with the Tukey A procedures indicated that two out of three pairwise comparisons of interest were significant ($p<.05$). As illustrated in Figure 2, the amount of air inhaled during reading for the control group was significantly less than the amount of air inhaled during reading for the ADSD group and in conversation for the control group. To be specific, the ADSD group had average ViVol measures of 564.11 Aml (arbitrary milliliters) for reading and 586.43 Aml for conversation, while the control group had ViVol measures of 393.42 Aml for reading and 530.46 Aml for conversation. This would suggest that the speakers with ADSD were using equivalent inhaled air volumes while the control speakers inhaled less air for reading.

Figure 2. Chart of the mean inspiratory volumes compared between participant group and speaking task



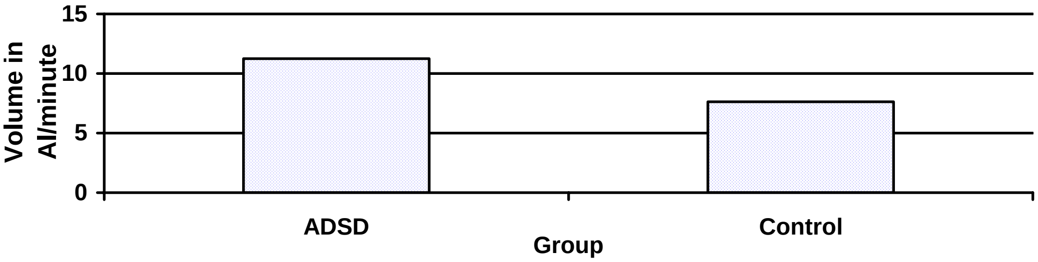
The second analysis considered expiratory volume (VeVol). The results of this MANOVA indicated that only the main effect of speech sample was significant, $F(1,26) = 5.499$, $p = .027$, $\eta_p^2 = .175$. Therefore, differences in volume expired depended on the task. Both groups expired a greater volume of air during conversation tasks when compared to reading tasks (see Figure 3).

Figure 3. Chart of the mean expiratory volume averaged across speaking task



The last MANOVA measuring volume was ventilation (Vent). In this case, there was a significant main effect for group, $F(1,26) = 5.519$, $p = .027$, $\eta_p^2 = .175$. As illustrated in Figure 4, the ADSD group had an average ventilation of 11.24 Al/min while the control group had an average ventilation of 7.645 Al/min. Therefore, those in the ADSD group have, on average, a higher ventilation rate no matter their speaking task.

Figure 4. A chart of the mean ventilation (Vent) rate compared across participant groups.

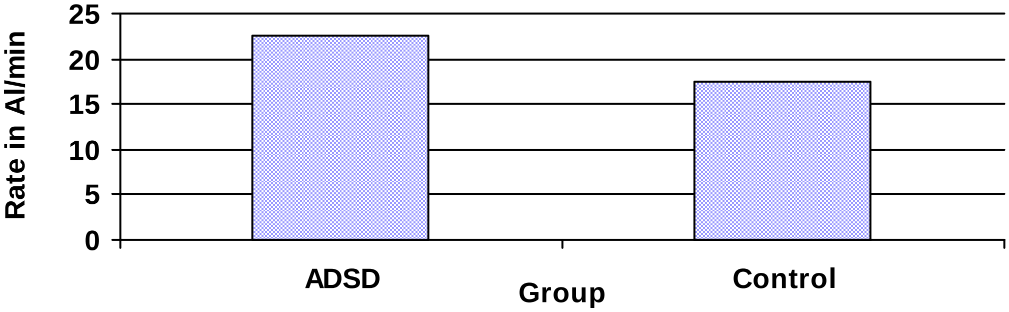


All MANOVAs performed for the volume parameters yielded a statistical difference. The control group inhaled a significantly lower volume of air while reading when compared to conversation and when compared to the group with ADSD in both tasks. Both groups exhaled a significantly lower volume of air during reading tasks than during conversation. There was a significant difference across groups when comparing the minute ventilation. Specifically, the ADSD group had significantly higher ventilation rates than the controls when the two tasks were averaged together. The effect sizes for all parameters were small, but suggested practical significance and that the inclusion of more participants may increase these effect sizes.

### *Timing*

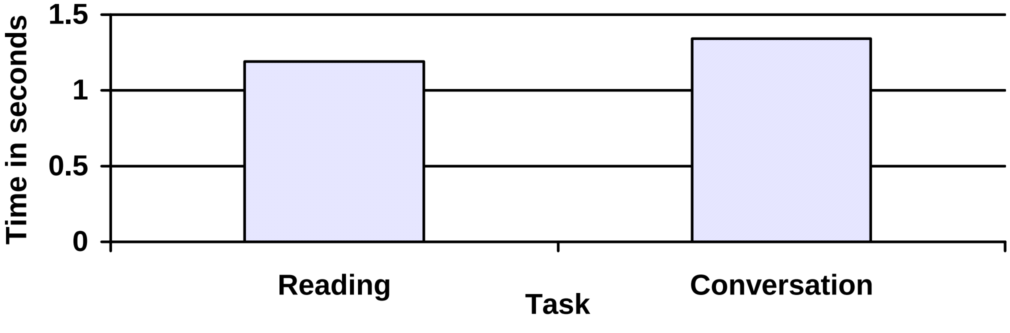
The next set of analyses considered measurements related to time. Specifically, breaths per minute (Br/M), inspiratory time (Ti), expiratory time (Te), total breath time (Tt), a fractional inspiratory time (Ti/Tt) and the time to reach peak expiratory flow (PefTTe) were the timing parameters that were analyzed. The first MANOVA considered breaths per minute (Br/M). The results revealed a significant main effect for group, $F(1,26) = 4.769$, $p = .038$, $\eta_p^2 = .155$. The ADSD group had an average of 22.66 breaths/min while the control group’s average was 17.58 breaths/min. As illustrated in Figure 5, the ADSD group, on average, inhaled more frequently during speaking tasks than did those in the control group.

Figure 5. A chart of average breaths per minute compared across participant group



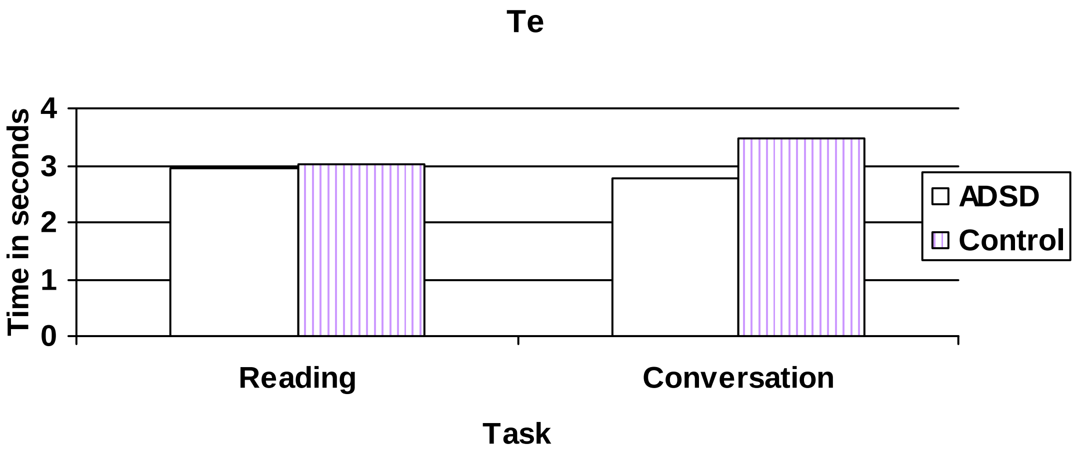
The next MANOVA considered inspiratory time (Ti) differences across groups, gender and tasks. Results revealed a significant main effect for task, $F(1,26) = 5.809$, $p = .023$, $\eta_p^2 = .183$. The average inspiratory time during the reading task was 1.19 seconds and 1.34 seconds during conversation (see Figure 6). The Ti value was greater in the conversational tasks than in the reading tasks.

Figure 6. A chart of the average inspiratory time compared across speaking tasks.



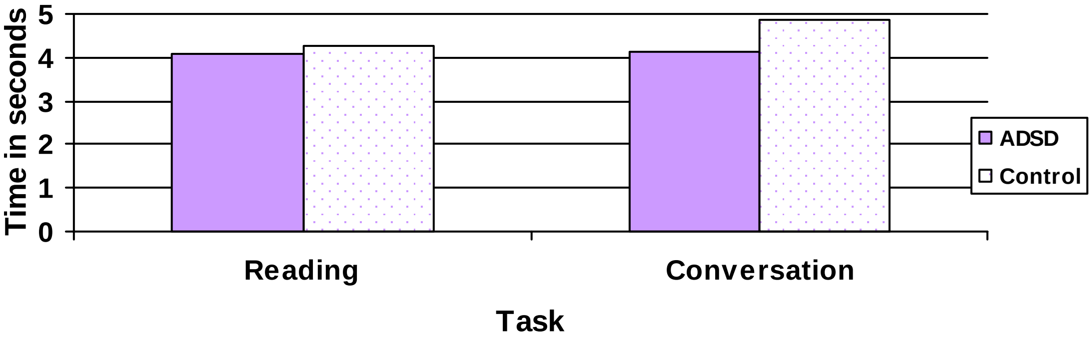
The next analysis considered expiratory time (Te). The results revealed no significant main effects or interactions. Therefore, there were no differences across groups, gender or tasks for the duration of expiration (see Figure 7).

Figure 7. A chart of the mean expiratory times compared between participant group and across speaking tasks.



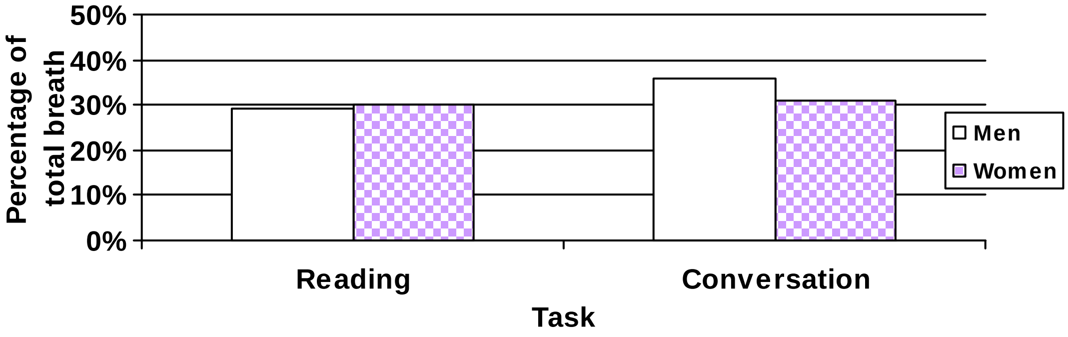
The next analysis of the timing measures considered total breath time (Tt). Once again, there were no significant main effects or interactions. Both groups had similar respiratory cycle durations regardless of speaking task or gender (see Figure 8).

Figure 8. A chart of the average total breath duration compared across participant group and speaking task.



The fifth MANOVA considered the fractional inspiratory time (Ti/Tt). The results indicated a significant interaction between task and gender, $F(1,26) = 7.442$, $p = .011$, $\eta_p^2 = .223$. In other words, differences among the Ti/Tt values for a specific task differed by gender. Post hoc testing with Tukey A procedures revealed that four out of six pairwise comparisons were significant ($p < .05$). As illustrated in Figure 9, the men's values for Ti/Tt in conversation were greater than the men's values for this parameter in reading and greater than the women's values in conversation. The men's values were equivalent to the women's in reading and the women showed no differences in Ti/Tt values when comparing conversation and reading. Hence, Ti/Tt values seem to be greatest for men in conversation.

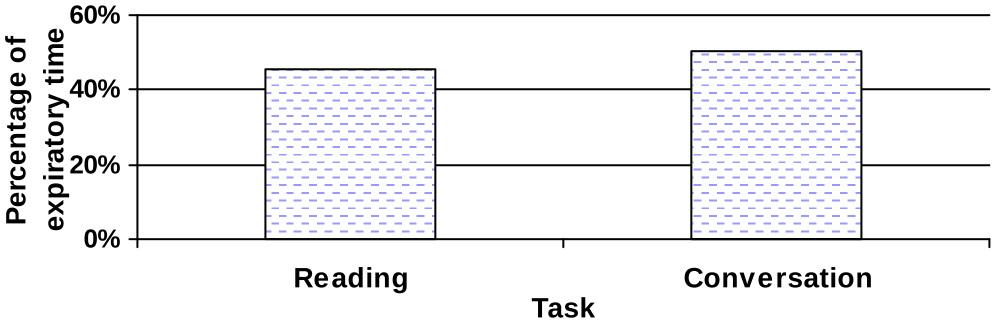
Figure 9. A chart of the average percentage of inspiratory time compared across gender.



The last MANOVA for the timing parameters considered the time to reach peak expiratory flow (PefTTe). In this case, only the main effect for task was significant, $F(1,26) = 5.599$, $p = .026$, $\eta_p^2 = .177$. The average time to reach peak expiratory flow (as a percentage of expiration time) was 45.72 % for reading and 50.09 % for conversation.

This indicates that, in general, speakers take longer to reach peak expiratory flow while in conversation than during reading tasks (see Figure 10).

Figure 10. A chart of the average percentage of expiratory time to reach peak expiratory flow compared across speaking tasks

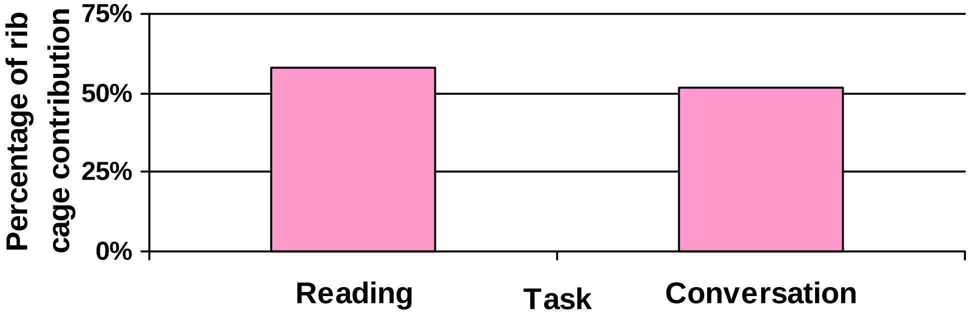


A total of four out of the six parameters relating to measures of time that were analyzed were found to be statistically significant when comparing across groups, gender and task. A main effect for group was found in one parameter, breaths per minute, with the ADSD group having a higher frequency of breaths per minute. Two parameters were found to be statistically significant with reference to task: inspiratory time and the time to reach peak expiratory flow. Specifically, a longer period of inhalation with a shorter time to reach peak expiratory flow was found in reading tasks. One parameter was found to have an interaction between task and gender. Men had a higher fractional inspiratory time in conversation than in reading and greater than women’s values in both speaking tasks. No significant main effects or interactions were found in two timing parameters: expiratory time and the average duration of the total breath. Again, the effect sizes for the parameters were small, but suggest practical significance. If more participants were included in this study, larger effect sizes may have been found.

*Thoracic Displacement*

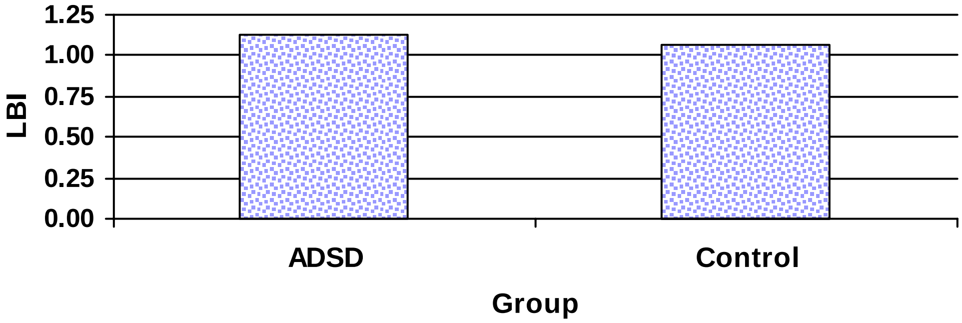
Two parameters were included in this study that related directly to rib cage and abdominal movements: the percent of rib cage contribution (%RC) and the labored breathing index (LBI). The first MANOVA considered the amount of rib cage contribution to the tidal volume. The results indicated that the main effect of task was significant, $F(1,26) = 18.329$, $p<.001$, $\eta_p^2 = .413$. The rib cage contributed to 57.7 % of the tidal volume during reading tasks and 51.7 % during conversational tasks. This indicates that breathing patterns during reading tasks utilize more rib cage movement (see Figure 11).

Figure 11. A chart showing the percentage of rib cage contribution across speaking tasks.



The second analysis considered the labored breathing index (LBI). The results revealed a group difference, $F(1,26) = 7.716$, $p = .010$, $\eta_p^2 = .229$. The group with ADSD had a higher index of labored breathing than the controls. Specifically, those in the ADSD group used more movements to produce less ventilatory output than the controls (see Figure 12).

Figure 12. A chart of the index of labored breathing compared across participant group.



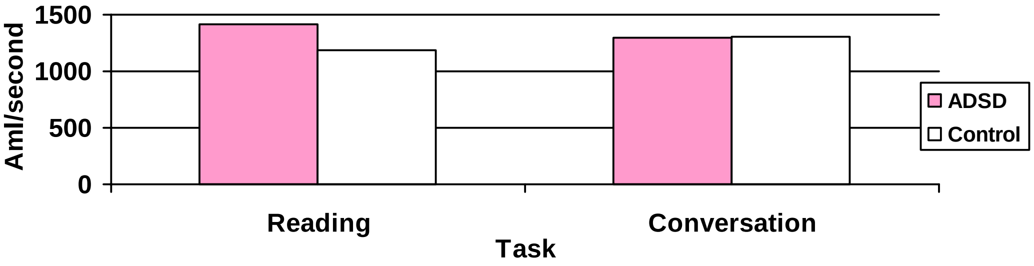
Analysis of parameters related to rib cage and abdominal movement yielded significance in both parameters. The main effect of task was significant for the percentage of rib cage contribution with the rib cage contributing more during reading tasks. The effect size ($\eta_p^2$ = .413) supporting this finding was large. Also, a group difference was found when comparing the LBI. Specifically, the ADSD group demonstrated a higher degree of labored breathing than the controls. In this case, the effect size ($\eta_p^2$ = .229) was moderate, supporting the significance of this finding as well.

*Respiratory Efficiency*

The next category of measures involved measures of respiratory efficiency. These parameters were derived through the comparison of tidal volume with one or more parameters related to volume, timing or thoracic displacement. The values obtained represented a rapid shallow breathing index (F/Vt), peak inspiratory flow (PifVt) and respiratory muscular efficiency (VePif). The first MANOVA considered the rapid shallow breathing index (F/Vt). There were no significant main effects or interactions. Therefore, there were no differences across groups, tasks or gender for the rapid shallow breathing index.

The results of the MANOVA for peak inspiratory flow (PifVt) also revealed no significant main effects or interactions. However, the task by group interaction approached significance, $F(1,26) = 3.746$, $p = .001$, $\eta_p^2 = .126$. While the effect size is small, it would suggest that there may be differences by task and group if more participants were run. As illustrated in Figure 13, there are comparable values in regards to conversation; however, there are obvious differences in the reading tasks between the two groups. This finding merits continued investigation.

Figure 13. A chart demonstrating the values for peak inspiratory flow compared across participant group and speaking task.



The last analysis for the derivational measures considered muscular efficiency and breathlessness (VePif). This analysis revealed a significant interaction between task and gender, $F(1,26) = 6.681$, $p = .016$, $\eta_p^2 = .204$. Post hoc testing revealed that males evidenced higher values for PefVt in the conversational tasks than males in the reading tasks or the females in both tasks (see Figure 14). In addition, the analysis revealed that the main effect for group was significant, $F(1,26) = 11.880$, $p = .002$, $\eta_p^2 = .314$. Those with ADSD experienced a greater degree of muscular inefficiency and breathlessness in both speaking tasks when compared to the control group (see Figure 15).

Figure 14. A chart depicting the differences in respiratory muscular efficiency and breathlessness compared across speaking tasks and participant group.

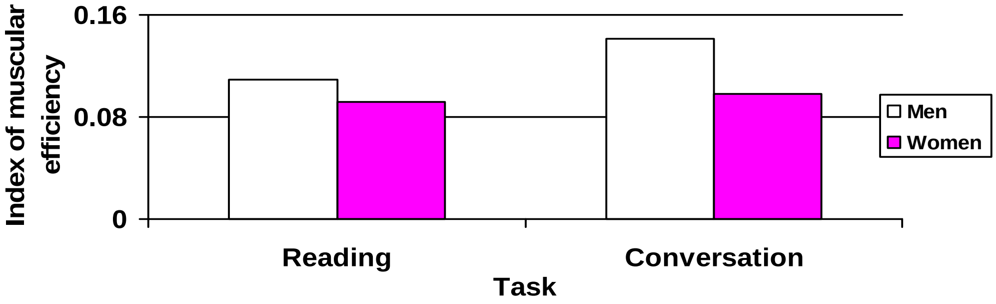
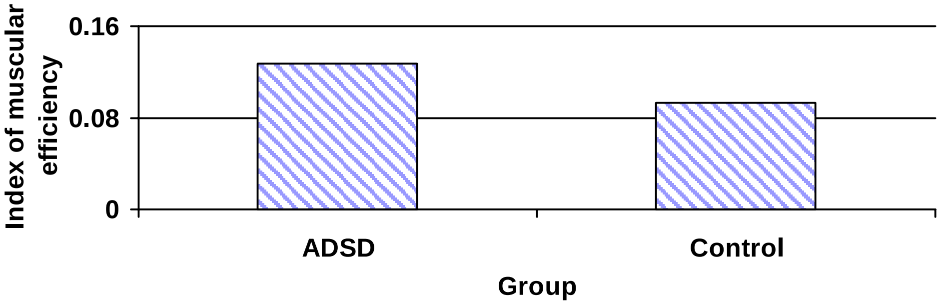


Figure 15. A chart showing the difference in respiratory muscular efficiency and breathlessness compared across participant group.



Results of the statistical analysis regarding the derivative parameters revealed only one parameter with significant findings for the independent variables. Specifically, an interaction between task and gender was found for VePif with men having a higher degree of muscular inefficiency during the conversation when compared to reading and for both measures in women. In addition, a significant main effect for group was found for this parameter. Specifically, the ADSD group was found to have a higher degree of muscular inefficiency and breathlessness than the controls in both tasks. The effect sizes for this parameter were moderate ($\eta_p^2$ = .314), supporting the significance of these findings. No significant differences were found in the rapid shallow breathing index, while the results of the analysis of peak inspiratory flow approached significance, indicating that there may be an interaction between task and group. The ADSD group, during reading tasks, appeared to have had higher values of peak inspiratory flow than the controls during reading or both groups during conversational tasks. The effect sizes for these parameters were relatively small, possibly indicating that a larger sample size would be needed in order to establish significance.

### *Summary of Findings*

MANOVAs were performed for each of the 14 breathing parameters included in this study. Many significant differences were found when comparing across group, gender and task. A main effect according to group was found in four parameters: VENT, Br/M, VePif and LBI. The ADSD group was found to ventilate more liters of air per minute and take more breaths per minute than the control group, regardless of speaking task. This group performed the speaking tasks with a higher index of labored breathing and respiratory inefficiency and breathlessness. In addition, main effects according to task were found in VeVol, Ti, PefTTe and %RC. Both groups had longer inspiratory times, larger expiratory volumes and took longer to reach peak expiratory flow during conversational tasks. Also during conversation, the rib cage contributed less to the tidal volume than during reading tasks. Additionally, several interactions were found to be significant. An interaction between task and group was found to be statistically significant in ViVol and approaching significance in PifVt. Those in the control group inhaled significantly less air in conversation than the ADSD or both groups in conversation. In addition, the ADSD group increased their respiratory drive in reading tasks when compared to the control group in reading or both groups in conversational tasks. Also, an interaction was found between task and gender in Ti/Tt and VePif. Men demonstrated a greater fractional inspiratory time with a greater muscular efficiency in conversation versus in reading or when compared to women in both tasks. Overall, these results indicate that individuals with ADSD evidenced more difficulties with breathing efficiency than the control group. These findings are consistent with the variable presence of obstruction at the level of the larynx.

# Discussion

The primary objective of the current pilot study was to determine if individuals with adductor spasmodic dysphonia differed from age- and gender-matched controls in various breathing parameters while engaged in speaking tasks. It was hypothesized that individuals with ADSD might suffer from disordered breathing due to obstruction at the level of the larynx. To determine if the participants utilized altered breathing patterns while speaking, volume, timing, thoracic displacement and measures of respiratory efficiency were computed and compared across group, speaking task and gender. The results indicated that, indeed, various significant differences existed between these two groups. Main effects according to group were found in four out of the 14 parameters analyzed. Those with ADSD were found to have statistically higher ventilation rates and frequency of breaths per minute. In addition, this group experienced a higher degree of muscular inefficiency/breathlessness and labored breathing. Differences according to task were found as well. Specifically, the participants utilized longer inspiratory times, exhaled a larger volume of air and took longer to reach peak expiratory flow during conversational tasks compared to reading tasks. There was also less rib cage contribution to the tidal volume in the conversational tasks. There were no main effects related to gender, however, various interactions between task, gender and group were found. These findings will be discussed further in light of the research questions.

### *Volume*

First, the research questions focused on potential differences in volume across groups, task and gender. Three different parameters were measured: inspiratory volume (ViVol), expiratory volume (VeVol) and the minute ventilation (Vent). Statistical analyses of these parameters revealed main effects for task and group, as well as an interaction between task and group. No differences according to gender were found related to volume measures. These findings suggested that, in relation to volume measures, differences do exist between groups, as well as in speaking task.

Most critical to the current study are the differences found between the two groups. Individuals with ADSD utilized higher ventilation rates in both speaking tasks when compared to the controls. The ventilation values obtained by RespiEvents refer to the total volume of air inhaled during a minute of speaking. Since the ADSD group experienced higher Vent values, they utilized more air while speaking. Interestingly, the two groups did not differ in their values of average inspiratory volume (ViVol). In other words, the ADSD group utilized a greater volume of air throughout the speaking tasks, without actually increasing the volume of air inspired on each breath. To accomplish this, therefore, the ADSD group increased the number of breaths taken per minute (Br/M). For that reason, the ADSD group was not able to use their breaths as efficiently as the control group because they required more air to complete the tasks.

Increased ventilation rates coupled with similar inspiratory volumes reveals that the ADSD group used their inspired air at a quicker rate. This finding was verified by an analysis of the audiotapes to compute average number of syllables produced per minute. On average, across speaking tasks, the group with ADSD produced 189.47 syllables per minute. On the other hand, the control group produced 230.51 syllables per minute. Therefore, this assumption was upheld as the ADSD group did produce fewer syllables per minute during the speaking tasks. In general, these individuals increased ventilation rates to overcome the glottal resistance, which in turn lead to a decrease in the number of syllables per minute. And, because of the higher rate of ventilation, they replenished their air supply more frequently in order to initiate speech. The individuals with ADSD attempted to overcome the increased laryngeal resistance associated with the spasms by increasing the overall minute inspiratory volume.

In addition to the group effect for ventilation, a task effect was found related to expiratory volume (VeVol). Participants exhaled a smaller volume of air during reading tasks compared to conversational tasks. These findings support evidence that respiratory behaviors related to volume are altered in different speaking tasks. Schaeffer et al. (2002) examined expiratory volumes in oral reading tasks. On average, smaller values were found in the less linguistically complex speaking task. Although this difference was not statistical, this tendency can be applied to the current study’s findings. The reading task presented the participants with a lower cognitive-linguistic demand. Linguistic markers, such as commas and periods, in addition to the grammatical markers, such as phrase boundaries, provided the participants with acceptable places to replenish their breath supply. Conversational speech, on the other hand, demanded a higher degree of cognitive planning, because it did not provide these markers. In conversational tasks, therefore, the participants experienced a higher demand on discourse planning, along with the absence of given markers indicating when to perform the respiratory events. This suggestion is further supported by the fact that the average syllables per minute for the reading task across all participants was 255.58, while for the conversation tasks, the average was 194.15.

Task differences were also found by Hixon and Hoit (2005) who reported an overall slower speech rate for speaking tasks that have a high cognitive-linguistic demand. Hence, both groups in this study expired more air during conversation because the cognitive-linguistic demand was higher. Reading of the Rainbow Passage (Fairbanks, 1960), on the other hand, was a more familiar (i.e., they had read it before in other speech evaluations) and linguistically determined task that structured breathing patterns. Therefore, it seems as though a more efficient utterance plan was developed for the reading tasks, as all participants produced more syllables on less air during these tasks.

Lastly, a task by group interaction was found. The control group inhaled a lower volume (ViVol) during reading tasks. This implies that the control group utilized an even more efficient utterance plan than the ADSD group to complete the reading tasks because they completed the tasks with a lower volume of air. It appears the ADSD group did not demonstrate this tendency to inhale less air during reading because the increased ventilation was required to overcome laryngeal obstruction regardless of speaking task.

The results of the statistical analyses revealed that differences between the groups and tasks exist in relation to volume measures. Specifically, those with ADSD were found to have a higher rate of ventilation than the controls, signifying the need for more air to complete the speaking tasks. This was the case, presumably because this group increased airflow through the glottis in order to prevent the spasms from halting phonation. Also, the measures related to expiratory volume yielded a difference between tasks, as both groups expired a smaller volume of air during the reading tasks. In addition, the control group inhaled a significantly lower amount of air during these tasks. These latter differences demonstrate how the cognitive-linguistic demand influenced the respiratory behaviors related to volume. The speaking demands on reading were lower, and, therefore, the participants used less air. The control group developed an overall more efficient utterance plan as evidenced by their overall lower inspiratory lung volume during the reading tasks.

### *Timing*

The research questions also focused on differences in the timing of breathing patterns. Six measurements related to timing of respiratory patterns were considered: breaths per minute (Br/M), inspiratory time (Ti), expiratory time (Te), total breath time (Tt), a fractional inspiratory time (Ti/Tt) and the time to reach peak expiratory flow (PefTTe). The results of statistical analyses revealed that differences were found depending on the type of timing measure. Most striking was the finding that those with ADSD tended to have a higher number of breaths per minute (Br/M). In other words, these individuals replenished their breath supply more frequently than controls. This seems obvious, considering increased ventilations rates were also found. This finding further suggests that the ADSD group required a greater volume of air during speaking tasks, presumably to overcome the laryngeal resistance.

In addition to the main effect regarding group, main effects regarding task were found in inspiratory time (Ti) and the time to reach peak expiratory flow (PefTTe). Both groups utilized longer periods of inhalation and took longer to reach peak expiratory flow during conversational tasks. This may be related to a reduced need for discourse planning during reading tasks because linguistic material was provided. Perhaps, because more cognitive and linguistic planning was required during conversation, the individuals increased inspiratory times as a method to increase planning time.

According to Hixon and Hoit (2005) there are manifestations in speech breathing during “activities that require on-line formulation” (p. 90). For example, the effects of demanding cognitive-linguistic processing can yield brief silent pauses (200-500 ms), breath holds and non-speech expirations. Although these symptoms were not specifically analyzed, it is likely that the increased cognitive load generated these behaviors in the conversational samples. These behaviors will influence the time to reach peak expiratory flow because they are directly interfering with expiration. In addition, as mentioned above and evidenced by the syllables per minute data, the participants had a lower speaking rate in conversational tasks. Again, Hixon and Hoit (2005) reported that this data should be expected in more demanding speaking tasks. Therefore, the increased cognitive load in the conversational tasks yielded changes in the timing of the speech breathing behaviors. Increased inspiratory times were used as *extra* time to formulate the upcoming speech. In addition, the demand on formulating the discourse manifested itself in the expiratory flow because it took longer to reach peak flow rates in conversation. Reading, on the other hand, did not require utterance planning to the same extent; hence, the participants were able to initiate speech quicker and more efficiently during this task.

Lastly, a task by gender interaction was found, in that, men in both groups tended to have a larger fractional inspiratory time (Ti/Tt) than women during the conversation tasks or both genders during reading. In other words, in conversational tasks, men spent a larger percentage of the total breath duration inhaling than the women did. This can be explained through the basic anatomical differences between men and women. Men, in general, have a larger lung capacity because they have larger body sizes (Hixon and Hoit, 2005). This fact, coupled with the above-mentioned finding that both genders experienced longer inspiratory time during conversation tasks, explains why men would experience a longer percentage of inspiratory time during conversational tasks.

Given these findings related to the timing of respiratory events, it is interesting that no differences according to group, task or gender were found in relation to the expiratory (Te) and total breath (Tt) durations. Phrasing during speaking tasks is controlled via a linguistic plan. The lack of a statistical difference here would suggest that individuals varied greatly in their expiratory patterns.

The results of statistical analyses of measures related to the timing of respiratory events revealed differences between groups, tasks and an interaction between gender and speaking tasks. Specifically, those with ADSD were found to replenish their air supply more often than the control group. This is not surprising, given the finding related to increased ventilation rates within this group. Also, the measures related to inspiratory time and the time to reach peak expiratory flow yielded a difference between tasks, as both groups took longer to inhale and to reach peak expiratory flow during conversation. Again, these differences were attributed to the differences in the demand of the cognitive and discourse planning between the two tasks. In addition, the men used a greater portion of the total breath inhaling during conversational tasks than the women, presumably because of the larger lung capacity in men.

### *Thoracic Displacement*

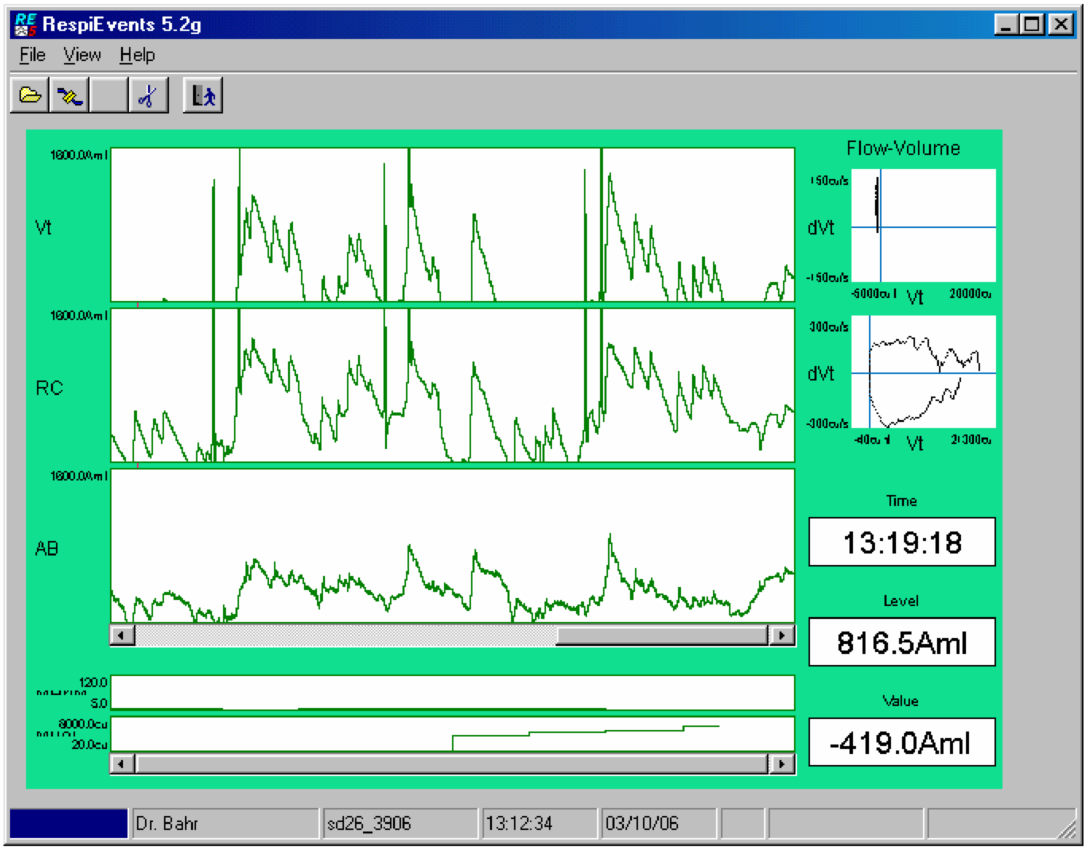
Next, the research questions focused on measurements related to the thoracic displacement during respiration. The results of statistical analysis revealed a group difference when considering the labored breathing index (LBI) with the ADSD group experiencing a higher degree of labored breathing. In addition, a difference regarding task in the percentage of rib cage contribution (%RC) was found with the rib cage contributing to a greater extent in the reading tasks.

A significant difference between groups was found with the ADSD group obtaining higher labored breathing (LBI) values. This was one of the most interesting findings because it supported the presence of disordered breathing patterns in this population. Because this measure considers the degree of rib cage and abdominal coordination during respiration, it can be said that those with ADSD are experiencing altered and disordered breathing patterns. Perfect coordination between the two systems would yield an LBI value of 1.0. On average, the ADSD group obtained an LBI value of 1.13, while the controls had a value of 1.06.

These findings can be compared to those found by Schaeffer et al. (2002), who examined thoracic displacement in individuals with dysphonia. Results from this study indicated that the individuals with dysphonia utilized paradoxical abdominal movements by using physical breathing patterns that are not typically observed. The purpose and contribution of the abdominal patterns to the respiratory cycle was not clear and considered aberrant. Therefore, the presence of laryngeal pathology affected the physiological patterns of respiration in this population by influencing physical displacement of the abdomen. This can be connected to the results of the present study, in that those with ADSD are experiencing discoordination between rib cage and abdomen. In a similar manner as Schaeffer's participants, the physiological underpinnings of respiration during speech are modified in individuals with ADSD. The laryngeal tension in the ADSD group resulted in the two sub-systems not functioning as a single unit, but, at times, working in dyssynchrony.

Figure 16 is an example of a RespiEvents waveform tracing in an ADSD participant. The quick vertical spikes in the waveform represent the band pulls indicating the beginning or end points of the speaking tasks. It is interesting to see the very different waveforms the rib cage (middle tracing) and abdomen (bottom tracing) are producing. When comparing these traces to the ones produced by a control participant (see Figure 1), the differences in the respiratory patterns are obvious. For example, on the control tracing, the actual contribution of each tracing to the tidal volume (top tracing) is obvious. On Figure 16, however, it is not clear how the abdomen is contributing to the tidal volume.

Figure 16. An example of a RespiEvents waveform produced by a participant with ADSD.



Time 13:19:18

Level 816.5Aml

Value -419.0Aml

Dr. Bahr | sd26_3906 | 13:12:34 | 03/10/06

According to Hixon and Hoit (2005), "whether reading aloud or speaking [in conversation], speech breathing tends to show similar mechanical patterning … and engagement of similar muscular strategies" (p. 89). With this in mind, it is interesting that the rib cage exhibited different levels of contribution between the speaking tasks. In this study, the rib cage (%RC) contributed to a greater extent in the reading tasks. This finding can be explained through the differences in discourse planning. It would seem that the increased recruitment of abdominal muscle occurred when the demand on the cognitive and linguistic planning systems were higher. The abdomen may have been utilized as a method to support expiration, in view of the fact that it took longer to reach peak expiratory flow during the more cognitively demanding tasks. Increasing the abdominal workload allowed the participants to control expiration while formulating the discourse and linguistic plan needed to perform the conversational tasks.

Statistical analysis of measures related to thoracic displacement revealed that differences existed between group and task. A higher degree of labored breathing was found in the ADSD group. This was attributed to physiological changes in the respiratory behaviors due to the obstruction at the level of the glottis. Measurements related to the contribution of the rib cage to the tidal volume showed a greater rib cage contribution in the reading tasks, presumably related to differences in discourse planning. It appeared the abdomen was recruited to a greater extent in conversational tasks to allow for the respiratory changes that occurred when the individual was formulating the linguistic plan. No differences related to gender were found regarding measures of thoracic displacement.

### *Respiratory Efficiency*

The last set of research questions addressed measures of respiratory efficiency. These measures involved timing or flow rates being derived from tidal volume and provided a rapid shallow breathing index (F/Vt), peak inspiratory flow (PifVt) and an index of respiratory muscular efficiency and breathlessness (VePif). With regards to these parameters, there was a high degree of variability in both groups that may have masked group differences.

Results of the statistical analysis indicated that the ADSD group demonstrated an overall higher level of muscular inefficiency and breathlessness when compared to controls. Again, these results are related to the disruption in normal respiratory patterns in those with obstructed larynges.  This finding, coupled with the significant group effect for labored breathing, exemplified the reduced level of respiratory functioning in individual with ADSD.  It appeared that those with ADSD were both inefficient in the muscular contributions to respiration and in regards to the ease at which respiration occurs.

In addition, an interaction between task and gender revealed that men during conversational tasks exhibited a higher degree of inefficiency and breathlessness than men in reading or women in both tasks.  It is speculated that, again, the level of cognitive-linguistic utterance planning influenced this parameter.  Because conversation required a higher degree of discourse planning, males in this task became less efficient in their respiratory behaviors.  It is not clear, however, why women did not also demonstrate this trend.

An interaction between task and group in values reflecting peak inspiratory flow (PifVt) approached significance.  Here, the ADSD group had larger PifVt values during reading when compared to the control group in reading and both groups in conversation. According to the RespiEvent manual, the higher the PifVt value, the higher the respiratory drive (Nims, 2002).  With this in mind, the ADSD group experienced greater respiratory drive during reading tasks.  These individuals used a higher degree of effort in order to keep up with the flow of reading.  The reading tasks were structured and respiratory events related to oral reading appeared to be linguistically controlled.  On the other hand, conversational tasks allowed greater respiratory freedom.  These tasks did not have linguistic and grammatical markers indicating when to perform the respiratory events.  Therefore, the effort needed to produce conversational speech was lower.

Because of the obstruction at the larynx, this group needed to increase respiratory drive in the reading tasks to maintain the proper flow as it was determined by the linguistic utterance plan.

Lastly, no differences were found in the rapid shallow breathing index (F/Vt). While the ADSD group was found to inhale more frequently during speaking tasks, they did not inhale so frequently as to indicate rapid breathing. In addition, the ADSD group, when compared to the control group, was found to inhale a comparable volume of air (ViVol), further supporting that shallow breathing was not evident in this population.

The results of the statistical analyses revealed that differences between the groups, tasks and gender existed in relation to measures of respiratory efficiency. Specifically, those with ADSD were found to have a higher degree of muscular inefficiency and breathlessness. This finding reflects disordered breathing within these participants. Also, males were found to be less efficient in conversation than women. This finding was attributed to an increased need for discourse planning during conversational tasks that led to less efficient respiratory patterns. An interaction between group and task approached significance for the parameter of peak inspiratory flow. Those with ADSD were found to have higher PifVt values, or a higher respiratory drive in the reading tasks. It was hypothesized that there was an increase in the level of control required to complete the reading tasks. The ADSD group, therefore, needed to increase effort in order to perform the respiratory events at the designated boundaries. Although two out of the three measures related to respiratory efficiency were not significant, the results still are valuable to the understanding of altered respiratory patterns in individuals with ADSD.

Most significant to the present study is the finding that those with ADSD have decreased muscular efficiency and breathlessness.

## Conclusions

The results of the present study indicate those with ADSD exhibit disordered breathing when compared to an age- and gender-matched control group. The objective data obtained in this study can be linked to these patient's subjective reports of a higher degree of effort needed during speaking. This effort is perceived as the effects of Botox treatment dissipates. Because of this, it appeared that the respiratory manifestations found in this current study during speech breathing are influenced by the neurologically-related laryngeal obstruction.

Statistical differences between the two groups were found in measurements of volume, timing, thoracic displacement and respiratory efficiency. In general, the ADSD group ventilated more air per minute (Vent), thereby requiring more breaths per minute (Br/M). In addition, their respiratory behaviors were performed with a lower degree of muscular efficiency and breathlessness (VePif) and with a higher index of labored breathing (LBI). These results illustrated a high level of discoordination between the respiratory and phonatory systems, indicating that the participants with ADSD exhibited some speech breathing parameters that were deviant from normal respiratory behaviors. Further, it added to the evidence base that those with disordered larynges experience alterations in their respiratory patterns and behaviors during speech.

In addition to the group differences, significant findings were found when comparing tasks. A higher volume of exhaled air (VeVol) and longer inspiratory times (Ti) were found in conversational tasks. Also during these tasks, the rib cage contributed less to the tidal volume (%RC) and participants took longer to reach peak expiratory flow (PefTTe). These differences supported the previous research that suggested that respiratory patterns were altered when engaged in different speaking tasks (Hixon & Hoit, 2005). These task differences were attributable to the demands of cognitive-linguistic planning. This hypothesis was supported by Schaeffer et al. (2002) who confirmed changes in respiratory behaviors when the demand on planning was altered. In that study, longer speaking tasks, without grammatical indicators for when to replenish air supply, resulted in deviant respiratory patterns. This type of speaking condition can be likened to the conversational task used in this study because the demand for linguistic planning was high and linguistic indicators marking appropriate places for breath renewal were not present. On the other hand, grammatical markers were included in the reading tasks, which reduced cognitive load by providing a linguistically appropriate indicator to replenish air supply or alter the respiratory patterns for speech producing purposes.

### *Clinical Implications*

The results of this study are clinically important to those who experience ADSD as well as for those who will work with this population. Those who will work with ADSD in voice therapy will want to be cognizant of the difference in respiration between reading and conversational tasks when choosing therapeutic tasks. Respiration appears to be more difficult in conversation for individuals with ADSD. Because the demands on cognitive and linguistic planning are higher during conversational tasks, reading seems to produce respiratory behaviors that more closely resemble the patterns in non-disordered individuals. In addition, reading provides individuals with linguistic cues that seem to affect the respiratory behaviors. For example, periods and commas will indicate appropriate pauses or places to renew the breath supply. These factors seem to positively influence breathing patterns during speaking tasks. Clinicians working with this population should understand the possible negative implications of spontaneous speech on the respiratory system. In order to create the most supportive therapeutic tasks, reading could be used to allow for more control of speech breathing. Once the client is ready to move into less structured therapy tasks, spontaneous speech can be attempted.

Treatment of ADSD has shown to be most effective when Botox injections are combined with behavioral voice therapy (Cannito & Woodson, 2000; Murry & Woodson, 1995; Sapienza et al., 2000; Woo et al., 1992). Results of studies that have examined respiratory behaviors pre- and post-Botox injection indicate a greater degree of airflow stability (Cantarella et al., 2006), as well as overall increased airflow rates with decreased laryngeal resistance (Adams et al., 1996). This establishes that, post-injection, individuals are experiencing closer to normal respiratory functioning. As reported above, increased respiratory effort is perceived in these patients as the Botox wears off. Thus, it is reasonable to suppose that physical respiratory symptoms may be a precursor for the emergence of the voice symptoms and signals a need for reinjection of Botox.

In the researchers’ experience in speaking with individuals with ADSD, a common complaint is a tightness in their chest while speaking. Although this phenomena of sensing breathing difficulty was not specifically examined in this study, the implications are obvious. Results of this study confirmed disordered breathing in individuals with ADSD, especially in regards to respiratory efficiency and labored breathing. In addition, at the time of testing, many subjects’ vocal quality was subjectively determined to be mildly strained/strangled. This indicates that the voice symptoms need not be severe for the significant respiratory behaviors to be evident. Therefore, the physical manifestations of the disorder (i.e. tightness) may be a strong indicator of the physiological manifestations (i.e. disordered breathing patterns) that occur as the effects of Botox wears off. A longitudinal study investigating this relationship would provide insight into this hypothesis.

Overall, the results of the analysis regarding measures of volume, timing, thoracic displacement and respiratory efficiency indicate that the Respitrace is a sensitive measure to determine differences in speech breathing. Those who will work with this population may want to invest in this instrumentation and use it to monitor breathing patterns over the course of therapy and possibly train to breathe more efficiently during laryngeal spasms.

### *Strengths of the Present Study*

There are a few strengths of this study. First, this pilot study included many parameters related to respiration that have not previously been examined in research related to ADSD. Previous studies have examined respiratory behaviors related to airflow and volume; however they have not examined timing, the physical displacement of the respiratory structures, or indices related to respiratory efficiency. This study, therefore, provides evidence regarding disordered speech breathing in this population that has not previously been reported. The results of this study showed the participants with ADSD exhibited a higher degree of muscular inefficiency and breathlessness and labored breathing. Also, they were found to ventilate more air per minute and subsequently renew their breath supply more often.

A second strength is that a control group was carefully established for a more reliable comparison of the data between groups. This adds further support to these findings because many studies compare their findings to the existing normative data. Normative data is not necessarily determined using the same methods and tasks as an experimental study. Therefore, since both groups completed similar tasks, the comparison between groups may be more valid. Further, both men and women were included in this study, which allowed for a more thorough evaluation of the disorder. According to the National Spasmodic Dysphonia website, more women than men are diagnosed with this disorder (NSDA, 2006). Through the inclusion of six men in this study, gender comparisons were possible. Frequently only men or only women are selected for studies; however, this severely limits the degree to which the results can be generalized.

The study's design is a third strength. Two different speaking tasks (reading and conversation) were included due to the evidence that respiratory behaviors are altered depending of the speaking task (Hixon & Hoit, 2005). Use of different speaking tasks allowed for comparison between the tasks to determine which one would better approximate non-disordered respiration for therapeutic tasks.

### *Limitations of the Present Study*

Six limitations may have affected the results of this study. First, the study included a total of 30 participants. This is a small number of individuals and a larger number of individuals would have increased the reliability of the results. Nevertheless, 15 individuals is a fairly large number of participants with ADSD for a research study. Fifteen people served the purposes of this study, although more would have been better.

Second, limited health, medical and previous treatment history related to the disorder was obtained from the participants. Although a few basic questions were asked, more information regarding their health, injection history, smoking history, time post-onset, etc. would have allowed for a more comprehensive investigation of this population. If this data were obtained, differences according to lifestyle, health, and other factors may have been found to influence speech breathing. In addition, if these individuals underwent voice therapy, they most likely experienced some degree of respiratory behavior modification. The effects of this training may obviously influence respiratory parameters and this possibility was not controlled.

The individuals in the ADSD group participated in this study prior to receiving their regularly scheduled Botox injection. ENT physicians frequently recommend that individuals receive Botox re-injections every three months in order to maintain a more stable voice over time. Therefore, in this experiment, the full effects of the Botox may not have fully worn off in the participants at the time of testing. Interestingly, however, patterns of disordered breathing were still evident, providing support to this study's conclusions.

The Respitrace was determined to be a sensitive measure for the purposes of the current study; however, problems with this instrument have been well documented. Band slippage is one problem that may have influenced the study. Although careful consideration was taken to prevent slippage, it may still have occurred unbeknownst to the researchers. Band slippage could skew the data obtained in the Respitrace waveforms. In addition to the slippage, baselines have been noted to drift upwards with this instrumentation (Leino et al., 2001; Neumann et al., 1998). This possibility was taken into consideration and the waveforms were analyzed to make sure the drift did not influence the data. Even so, there could have been a small degree of baseline shift that influenced the data.

Lastly, the tasks chosen for this study were fairly short in duration. On average, the reading passage took approximately 30 seconds to complete and most people were engaged in conversation for one minute. This fact has two possible implications. First, baseline drift is thought to even itself out when the instrument is used for a longer period of time (Leino et al., 2001). Since the entire procedure, including calibration and completion of the speaking tasks, would have taken less than 15 minutes, stabilization of the drift (if the drift took place) probably did not occur. On the other hand, however, because the entire procedure was only 15 minutes or less, the baseline possibly would not have had the opportunity to drift upwards so much as to significantly skew the data.

On a different note, more in depth information may have been obtained had the speaking tasks been longer in duration. If longer speaking tasks were used, a more in depth examination of respiratory behaviors in extended speaking tasks would have been obtained. It is possible that breathing patterns would change as the length of the speech sample increased.

### *Directions for Future Research*

This study attempted to establish if respiratory behaviors were altered in individuals with ADSD. Although, it was found that there were critical important differences in breathing patterns between the controls and patients with ADSD, future research should consider other factors. First, longer speaking tasks should be included. This will help to establish more data on the breathing parameters utilized during normal speech. Stressing the system, so to say, will give a more realistic look at the respiratory behaviors in this population. It must be said, however, that increasing the required duration of conversational tasks will also increase the demand on discourse planning. Therefore, the differences regarding task may be even more apparent in the longer utterances.

In the current study, participants were asked to partake in the study immediately preceding their Botox injections. Comparisons of the respiratory patterns pre- and post-injection will provide valuable information in regards to the effectiveness of Botox. In addition, this will provide more detailed information regarding respiration when the vocal symptoms are not present. Clinically, if individuals with ADSD resume normal respiration post-injection, behavioral therapy may focus on establishing and maintaining these normal respiratory behaviors. It would also be beneficial to examine the respiratory behaviors in individuals who do not have any amount of Botox within their laryngeal musculature. Individuals who have never been injected or have not been injected for at least six months will allow for examination of the respiratory behaviors associated with ADSD that have not been influenced by the effects of Botox.

If this study were to be replicated, a few differences should be considered. The Respitrace allows for the calculation of several parameters not specifically examined in this study. For example, this study did not examine the time to reach peak inspiratory flow (PifTTi), the peak expiratory flow (PefVt) or the percentage of agreement between the direction of rib cage and abdominal movements during inspiration (PhRIB), expiration (PhREB) and the total breath (PhRTB). Although these parameters were not deemed critical to include in this study, it would be interesting to see if differences according to group are found in regard to these parameters. Examining the agreement between the direction of the surface displacement in the inspiratory, expiratory and total breath phases can further indicate disordered breathing as it relates to the physiological properties of respiration.

Lastly, many participants felt awkward or uneasy about the conversational speaking tasks. They expressed anxiety about what to say and how long to talk. Picture description seemed to work well for many participants because it gave a referent to discuss. Others, however, were unsure or lacked confidence to perform this task. Therefore, the conversational tasks should be reconsidered to determine a more effective way of obtaining data related to spontaneous speech. In addition, more group differences may have been seen if an unfamiliar reading task was used. The Rainbow Passage (Fairbanks, 1960) is commonly used in voice assessments. It would seem, therefore, that the majority of the ADSD participants would be, at least, somewhat familiar with the passage. Future research should include a reading passage that would be unfamiliar to all participants.

### *A Final Word*

Adductor spasmodic dysphonia is a focal dystonia that manifests itself during voice production. It has serious detrimental influences in the lives of those it affects. If additional and more comprehensive information is obtained regarding this disorder, better treatment and management methods can be established. It is unfortunate that little is known regarding this disorder. Further research should be conducted to describe the respiratory behaviors used by individuals with ADSD and the impact these behaviors have on their lives.

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