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The effect of chronic obstructive pulmonary disease on swallowing

Jessica R. Torres
James Madison University

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The Effect of Chronic Obstructive Pulmonary Disease on Swallowing

An Honors Program Project Presented to

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James Madison University

by Jessica Renée Torres

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FACULTY COMMITTEE:	HONORS PROGRAM APPROVAL:
Project Advisor: Erin Kamarunas, Ph.D., Assistant Professor, Communication Sciences and Disorders	Bradley R. Newcomer, Ph.D., Director, Honors Program
Reader: Teresa Drulia, Ph.D., Principal Research Investigator	
Reader: Erin S. Clinard, M.A., CCC-SLP, Instructor, Communication Sciences and Disorders	

PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, at JMU Honors Symposium on December 2, 2016.

To the Original Rat Pack –
my sisters in Christ, my dear friends, and my #1 fans
you are a gift I did not deserve, but am so humbled to receive
thank you for the ways you love and encourage me
ilyamilly

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Third and finally, to every person who has prayed for me throughout my time at James Madison University and to those who prayed specifically for my thesis: I am so thankful for your willingness to come alongside me and include me in your prayers. I know God listened because He provided. Thank you for your part in that.

To God be the glory.

Jrt

Abstract

This work is composed of a literature review, research review, and self-reflective essay. The anatomy and physiology of normal swallowing and respiration are reviewed. Additionally, the effect of chronic obstructive pulmonary disease (COPD) on these processes is discussed. The research goal was to determine how lung volume changes adapt the physiology of swallowing in individuals with COPD. The research project was designed and conducted by Teresa Drulia, M.S., CCC-SLP. COPD participants (n=9, mean age=72, 6 male) were compared to older healthy individuals (n=10, mean age= 59, 3 male). Participants completed swallows of 20cc of water at four lung volume conditions: non-cued, resting expiratory level, tidal volume, and total lung capacity while respiration and pharyngeal pressures were recorded. The results indicated that COPD participants swallow at a lower lung volume than older healthy individuals. A significant inverse relationship was found between estimated lung volume at the time of the swallow and pharyngeal duration in individuals with COPD that was not present in the older healthy. Pharyngeal swallow duration was longer in COPD, although not statistically significant, and normalized to approximate that of healthy individuals only when they inspired to a larger lung volume. COPD participants followed a swallow with inspiration significantly less at higher lung volumes. The final section of this work is a reflection on the experience of being a research assistant and writing an undergraduate thesis.

Literature Review

Introduction

To understand how impaired respiration in chronic obstructive pulmonary disease (COPD) affects swallowing function, one must understand normal swallowing physiology and the normal interaction between respiration and swallowing.

Normal Swallowing

In normal deglutition, there are four phases: 1) the oral preparatory phase where food is masticated, manipulated, and prepared for swallowing; 2) the oral transit phase, where the food, now formed into a bolus, is transported into the pharynx; 3) the pharyngeal phase, where airway-protective actions occur and the bolus is propelled through the pharynx; and 4) the esophageal phase, where the bolus enters the esophagus and is transported to the stomach for digestion. These phases occur sequentially, smoothly, and quickly. A single bolus swallow lasts approximately two seconds from the beginning of oral transit to the entrance of the bolus into the esophagus. There are natural variations in the execution and duration of each phase depending on size and viscosity of the bolus and age of the person, to name a few.

The oral preparatory phase. The oral preparatory phase of swallowing is the first stage of the swallowing process. During this volitional stage, food or liquid is placed into the mouth and prepared for swallowing. This process typically involves mastication (chewing) and bolus manipulation, which engages both tongue and oral cavity musculature. Innervated by the facial nerve, the orbicularis oris works to maintain a labial seal during this phase. Since the mouth is closed to ensure there is no loss of bolus through the lips, breathing through the nose is necessary. Therefore, the velum is depressed to open the nasal cavity. When liquid is held in the oral cavity, the velum actively depresses to make contact with the tongue base, preventing spillage into the pharynx. However, during active mastication, the velum does not make contact with the tongue base and it is normal and common for small amounts of food to spill into the pharynx and collect in the valleculae – the space between the base of the tongue and the raised epiglottis. Also innervated by the facial nerve, the buccinator muscles work to maintain tension in the cheeks so masticated food does not fall into the lateral sulci, the space between the teeth and the cheeks. (Logemann, 1998).

During the oral preparatory phase, the muscles of mastication work together with the muscles of the tongue to break down solid material into an ingestible bolus. The primary muscles of mastication – all innervated by the trigeminal nerve – are the masseter, the temporalis, and the pterygoid muscles. Boluses are formed during the cyclic process of the tongue positioning the food between the teeth, the teeth occluding and grinding, and the tongue repositioning the food back to the occlusal surface of the teeth as the food is pushed out from between the teeth by mastication. During this process, saliva is mixed with the food to form a cohesive bolus. This process requires adequate sensory feedback information to be sent to the nucleus ambiguous in the medulla to prevent injury to the tongue or loss of bolus material.

The oral transit phase. In the oral transit phase of swallowing, the formed bolus is propelled through the oral cavity and into the pharynx, which triggers the pharyngeal swallow. The formed bolus is placed on the midline of the tongue and the tip and edges of the tongue form a tight seal along the anterior and lateral alveolus. Then the tongue, in an anterior-to-posterior motion, makes contact with the hard palate, squeezing the bolus towards the back of the oral cavity. The greater the viscosity of the bolus, the more lingual pressure required to propel the bolus posteriorly. This phase lasts 1-1.5 seconds and is volitional.

The pharyngeal phase. The pharyngeal phase of swallowing typically initiates as the bolus activates sensory receptors in the base of tongue and anterior faucial arches (palatoglossus) in the oropharynx. However, pharyngeal onset timing varies in older and impaired individuals, who may initiate the swallow as the bolus flows more inferiorly into the lower pharynx (Logemann, 1998). When the pharyngeal swallow is initiated, a sequence of involuntary physiological movements is set into motion and completed in 1.5 seconds or less. As the tongue continues to propel the bolus toward the back of the mouth, the velum is elevated to close the velopharyngeal port and prevent material from entering the nasal cavity. The tongue base and pharyngeal constrictors squeeze together to create high levels of pressure that propel the bolus through the pharynx toward the opening of the esophagus.

As the pharyngeal swallow is initiated, the hyolaryngeal structure is pulled superiorly and anteriorly by the suprahyoid muscles (Groher, 2016). The purpose of this movement is twofold: airway protection and the opening of the esophagus. To protect the airway from penetration or aspiration, the true vocal folds and the false vocal folds adduct to seal the airway and the displacement of the larynx causes the epiglottis to invert and seal the opening to the laryngeal vestibule. As the larynx is pulled up and forward, the cricopharyngeus muscle relaxes and the upper esophageal sphincter is pulled open, allowing the bolus to enter the esophagus.

The esophageal phase. The final phase of a swallow is the esophageal phase. This involuntary phase begins when the bolus enters the esophagus through the upper esophageal sphincter and ends when the bolus passes through the lower esophageal sphincter into the stomach. The movement of the esophageal muscles required to transport the bolus is called peristalsis – a superior to inferior constriction of the circular and longitudinal muscles of the esophagus that applies positive pressure to the tail of the bolus and propels it through the esophagus and into the stomach. This process generally takes 8-20 seconds depending on the viscosity of the bolus.

The neurological component. Swallowing requires a precise coordination of motor and sensory neurons, which connect and communicate in the nucleus ambiguous (NA) of the medulla. This nucleus has a central pattern generator (CPG) for swallowing. CPGs are “a set of interconnected neurons capable of generating a basic pattern of motor output underlying ‘automatic’ movements (breathing, locomotion, chewing, swallowing, and so on) in the absence of afferent signals from the executive motor apparatus” (Arshavsky et al., 2015, abstract). When the sensory neurons in the oropharynx detect a bolus, the information is relayed to the NA, which generates a pattern-elicited response and the pharyngeal phase of the swallow initiates. This response is largely thought to be mediated primarily in the brainstem CPGs, involving limited cortical control, because the motor neurons need to fire quickly to maintain airway safety. The CPG sequences pharyngeal and laryngeal muscle contraction in a specific progression so that the bolus is squeezed inferiorly and the laryngeal vestibule is closed prior to bolus arrival. The general pattern is approximately the same for every swallow, but adjusts in response to oropharyngeal sensory feedback such as the size and viscosity of the bolus, position of the oropharynx, and lung volume (Ertekin, 2015). This allows swallowing to be quick, automatic, and precisely coordinated, but adjustable to various conditions.

Neural control of respiration is both voluntary and involuntary, based on the current respiratory needs of the individual. A study by Paydarfar and colleagues demonstrated that swallowing resets the respiratory phase (1995). When the swallow CPG fires, it overrides the respiration CPG to inhibit respiration and protect the airway from penetration and aspiration. It is hypothesized, however, that in the pulmonary-disordered population, the increased drive for respiration may override the airway-protective actions during swallowing, resulting in discoordination between breathing and swallowing (Martin-Harris, 2000).

Respiration and Swallowing

The coordination of respiration and deglutition is essential for the health and success of both breathing and swallowing. Because the upper airway is used for both breathing and swallowing, there must be protective closure of the non-active system during these functions – i.e. the esophagus closes during breathing and trachea is closed off during swallowing. Laryngeal closure during swallowing protects the airway from penetration (material entering the larynx) or aspiration (material entering the trachea). Therefore, respiration and deglutition are reciprocal functions; that is, respiration must cease so that swallowing may occur (Logemann, 1998). This period of airway closure and respiration cessation is termed “apnea.”

Apnea duration during swallowing is approximately 1.0 second (Martin-Harris et al., 2005), but this duration is highly variable and differs between individuals. Apnea can begin at any time in the swallow process from the oral stages to the onset of the pharyngeal stage. However, Martin-Harris’ 2005 study found that the duration of apnea increases with age and the end of apnea, marked by the reinitiation of respiration, occurs significantly later in older individuals (>81 years old) than in younger individuals (21-40 years old).

Research has shown that the respiratory pattern – whether an individual is inhaling or exhaling before and after swallow apnea – has an effect on the safety of the swallow. Martin-Harris and colleagues found that 71-75% of healthy participants use an exhale-swallow-exhale pattern (2005). It was also observed that the respiratory pattern use differed by age. Younger participants (mean age: 56) predominantly used the optimal exhale-swallow-exhale pattern while older participants (mean age: 68) used both inhale-swallow-inhale and exhale-swallow-inhale patterns. Following a swallow with inspiration "may facilitate entry of portions of the ingested material or saliva into the laryngeal inlet prior to or during the late stages of pharyngeal swallow" (Martin-Harris, 2005, p. 768), while following a swallow with expiration lends opportunity to better protect and clear the airway should penetration or aspiration occur. Expiring after a swallow gives the individual the ability to quickly expire air or cough without having to inspire first. Therefore, observed divergence from a normal respiratory-swallow pattern may indicate a decrease in swallow safety.

In 2009, Wheeler and colleagues determined that respiratory patterns do not vary by bolus type and their study indicated that 87% of healthy swallows are followed by expiration as an airway-protective measure. Additionally, Uysal and associates postulated that swallowing during exhalation is beneficial for hyolaryngeal elevation because at the time of exhalation, the diaphragm is relaxed and the forces of upward movement have less resistance (2012).

Another important component to consider when discussing the coordination of respiration and swallowing is lung volume, or the amount of air in the lungs at the time of the swallow. Wheeler and colleagues studied lung volumes across bolus consistencies and found that thin liquids were swallowed at a greater lung volume than thin- or thick-paste boluses, possibly due to the higher likelihood of laryngeal penetration with thin liquids and the enhanced expiratory pressure created with higher lung volumes that assist in expelling penetrated or aspirated material. The authors discussed the possibility of a lung volume requirement for successful swallow execution, observing that "the amount of air present in the lungs as a swallow is initiated [remained] consistent across the four respiratory pattern possibilities surrounding a swallow" (2009, p. 184). Similarly, Martin-Harris concluded that "initiating swallowing in the expiratory phase at mid-to-low lung volumes poses significant physiologic advantages for hyolaryngeal anterior-superior movement, airway closure, and pharyngo-esophageal segment (PES) opening" (2008, p. 195). This phenomenon can be attributed to the amount of air in the lungs and how that affects subglottic pressure and the strain on hyoid and laryngeal musculature. Wheeler et al. (2009) hypothesized that a mid-range lung volume was indicative of an ideal recoil force of the lungs-thorax unit, under which conditions the swallow would be followed by expiratory airflow, effectively expelling penetrated or aspirated material. Therefore, a higher lung volume would be ideal for a more effective laryngeal cough reflex.

Lung volume has also been seen to affect the duration of the pharyngeal swallow. Gross and colleagues found that pharyngeal activity duration was significantly longer in swallows executed at residual volume when compared to the duration of swallows executed at total lung capacity and functional residual capacity (or resting expiratory level) (2003).

Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease (COPD) is a "condition of irreversible airway obstruction caused by destruction of lung tissue" (Dikeman, 2003, p. 35). The COPD Foundation reported in 2013 that 30 million people in the United States are affected by COPD.

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) Pocket Guide, published in 2015, describes COPD as "a common preventable and treatable disease, characterized by persistent airflow limitation" (p. 4) Physiologically, the lungs experience chronic inflammation, tissue destruction, air obstruction, and hyperinflation. The damage is typically attributed to tobacco smoking (90% of cases); air pollution (indoors and outdoors); and prolonged exposure to chemical agents, fumes, and dust (Duncan, 2016). These inhaled particles and gases irritate, infect, and obstruct the small airways in the lungs and make oxygen exchange – and by extension, breathing – difficult. Persons with COPD have difficulty meeting oxygen requirements as well as difficulty exhaling all of the carbon dioxide they inhaled due to air trapping, which leads to hyperinflation. Symptoms of COPD include chronic cough (which can often be unproductive), chronic sputum (mucus) production, and persistent shortness of breath (dyspnea) that worsens over time and with exercise (GOLD, 2015).

COPD is a progressive disease oftentimes characterized by exacerbations. GOLD defines exacerbation as “an acute event characterized by a worsening of the patient’s respiratory symptoms that is beyond normal day-to-day variations and leads to a change in medication” (2015, p. 4). Exacerbations are deviations of the respiratory condition from a person’s baseline, and full recovery is not often possible. Therefore, exacerbations lead to a worsening of the person’s overall respiratory condition, and often lead to hospitalization and/or intensive breathing treatments. As the disease progresses, patients are often put on constant or PRN (as needed) oxygen supplementation.

COPD is diagnosed by a physician or pulmonary specialist and is objectively measured by spirometry. The specific test to diagnose COPD is FEV_1/FVC. In this test, the amount of air that can be inhaled into the lungs and blown out forcefully over one second is measured and divided by the person’s forced vital capacity. In order to be classified as COPD, one must blow a 0.70 or lower. Meaning that in one second, they forcefully blow out 70% or less of their vital capacity. COPD severity is measured by how the FEV_1 value compares to the predicted value for an individual of their age, sex, weight, and height. Mild COPD is classified as $FEV_1 \geq 80\%$ predicted, moderate COPD is FEV_1 50-79% predicted, severe COPD is FEV_1 30-49% predicted, and very severe COPD is $FEV_1 < 30\%$ predicted (GOLD, 2015).

COPD and Swallowing

The body of research on swallowing in persons with COPD is a young but growing field. It is known that altered respiration has an effect on swallowing physiology in healthy individuals. Additionally, studies have suggested that those with impaired respiration may have compromised swallowing function or be at higher risk to the consequences of impaired swallowing (such as aspiration pneumonia) (Martin-Harris, 2008).

The literature on swallowing in COPD populations supports that COPD patients swallow with a maladaptive inhale-swallow-inhale pattern (Gross et al., 2009). As discussed previously, inhaling before or after swallowing may cause portions of the bolus to enter the larynx. There is an impaired ability to use expired air to clear the airway when a swallow is followed by inhale, and this may contribute to an increased risk of aspiration and aspiration pneumonia. Cvejic et al. (2011) found that inhaling before the swallow can also increase the risk of inhaling pharyngeal contents, leading to penetration and aspiration.

Martin-Harris and colleagues remarked that inhaling after a swallow may “facilitate entry of portions of the ingested material or saliva into the laryngeal inlet prior to or during the late stages of pharyngeal swallow. This would be of particular concern in patients with impaired pulmonary defenses, such as suppressed cough or decrease in upper airway sensation” (2005, p. 768). In some cases, patients with COPD are not able to sense penetration and aspiration due to a decrease in mechanosensitivity, and have difficulty producing a productive cough to expel any penetrated or aspirated material because their cough reflex is compromised. Under these conditions, the risk of aspiration pneumonia and exacerbations increases. Gross et al. (2009) discussed that this process is cyclic: breathing-swallowing discoordination can cause aspiration, which may contribute to exacerbations, while exacerbations may also promote aspiration.

In 2000, Martin-Harris and colleagues discussed that "patients often [reported] that they tire easily when eating or experience dyspnea during eating and drinking possibly reflective of increased physiological load placed on an already compromised respiratory system during mealtime" (p. 314). Experiencing shortness of breath or difficulty breathing during meal times is dangerous for the safety of swallowing. "Air hunger" is when a person is desperate for air, and that need takes precedence over safe swallowing when necessary. One who has "air hunger" during eating will "exhibit premature opening of the larynx during the latter stages of the swallow in an attempt to re-establish respiration as quickly as possible after the apneic period" (Martin-Harris, 2000, p. 317). This is an example of how the respiratory CPG can override the swallow CPG.

Many studies have also found that individuals with COPD have developed additional protective mechanisms which compensate for disordered swallowing physiology. One study observed significantly longer base of tongue contact with the posterior pharyngeal wall in COPD participants when they were ingesting large liquid swallows (Mokhelsi et al., 2002). De Dues Chaves and colleagues (2014) found an atypical lack of swallowing complaints from their COPD participants with no instances of aspiration during the study, but observed that they exhibited "longer durations of tongue base contact with the posterior pharyngeal wall" with small liquid boluses, a mechanism they attributed as a "protective physiologic swallowing maneuver" (p. 6, 7). Cvejic and colleagues remarked, "Our results suggested that normal protective mechanisms during swallow may be compromised in COPD and that penetration/aspiration may take place when drinking relatively large volumes of fluid," giving reason to why COPD patients require additional protective measures while swallowing (2011, p. 274).

Another protective measure the current body of literature on swallowing in COPD has discussed is apnea duration. It has been found that apnea is significantly prolonged during the swallows performed by patients with COPD and that the prolongation of apnea could indicate "the presence of a compensatory mechanism, such as providing… more time for the bolus to transverse the pharynx and enter the esophagus" (Gross et al., 2009, p. 564). COPD patients exhibited other possibly protective swallow deviations, such as earlier airway closure – sometimes significantly before the opening of the cricopharyngeus (CP) – and extending apnea well past the closing of the CP (Mokhelsi et al., 2002).

Several significant anatomic and physiologic changes have been observed in individuals with COPD. COPD drastically changes the anatomy and physiology of the respiratory system and inhaled medications used to treat symptoms of COPD can also affect the anatomy and physiology of the shared respiratory and deglutory systems (namely the mouth and pharynx). Studies on COPD and swallowing have observed swallow motor impairments including impaired hyolaryngeal elevation (Cvejic, 2011), abnormal muscle structure and function, decreased base of tongue retraction, muscle fatigue of the mouth and pharynx, and reduced tongue control (Cvejic et al., 2011; Gross et al., 2009). As previously mentioned, sensory deficits have also been documented in the COPD population and include reduced mechanosensitivity in the laryngopharynx that may be related to medication effects, chronic coughing, and delayed swallow initiation (de Deus Chaves et al., 2014; Mokhelsi et al., 2002). These impairments contribute to a difficulty swallowing and compromised swallowing safety. All of these physiologic changes should be considered when working with a person with COPD that has complaints of or exhibits symptoms of dysphagia.

Conclusion

In conclusion, swallowing requires an effective and timely coordination of multiple systems and structures to prevent penetration or aspiration. An important part of this process is the cessation of respiration for the duration of the pharyngeal swallow. This coordination can be disrupted in individuals with diseases that affect pulmonary function, such as chronic obstructive pulmonary disease (COPD). Research has shown that because the coordination of respiration and swallowing is impaired in persons with COPD, they are at a greater risk for aspiration and aspiration pneumonia that can lead to exacerbations and mortality.

Research Review

Disclaimer

While the writing is my own, the research outlined and discussed in this chapter was developed and conducted by Teresa C. Drulia, M.S., CCC-SLP, in fulfillment of her requirements to receive her Ph.D. in Communication Sciences and Disorders through James Madison University. All methods and results are her intellectual property. If the reader is interested in learning more about the study and its results, please consult Drulia's dissertation entitled, "The Effects of Lung Volume Changes on Swallowing in Chronic Obstructive Pulmonary Disease." This paper was produced with full permissions from the primary investigator.

Gaps in Research

It is known that lung volume has an effect on swallowing in healthy individuals, specifically changing the respiratory-swallow patterning and duration of swallow (Martin-Harris, 2008). Both of these changes can have dangerous implications for individuals with chronic obstructive pulmonary disease (COPD). In the field of research on swallowing in individuals with COPD, it has been discussed that individuals with COPD are at a higher risk for penetration and aspiration while swallowing, but a mechanism for dysphagia has not been determined (Cvejic, 2011).

Aims and Hypotheses

The aim of this study was to examine the relationship between lung volume and swallowing physiology in COPD. The three primary hypotheses were 1) lung volume at the time of the swallow will be significantly lower in COPD than in healthy; 2) at different lung volumes, pharyngeal swallow duration will be increased in individuals with COPD compared to older healthy participants; and 3) the respiratory-swallow patterns in COPD participants will change due to lung volume modulation (i.e., swallowing at higher lung capacity will result in less swallows followed by inspiration than swallowing at lower lung volumes).

Methods

Participants. Participants for this study were recruited using flyers, blast emails to the faculty and staff of James Madison University, and word of mouth. All participants completed a telephone screening to determine inclusion/exclusion criteria. Healthy participants needed to be at least 45 years old for comparison with individuals with COPD. Prior to beginning the study, every participant completed an informed consent form after the principal investigator outlined the study, explained risks and benefits, and discussed confidentiality. Participants were screened for dysphagia (Dysphagia Handicap Index, <8 required for healthy participants), reflux (Reflux Symptom Index, <13 required to participate), and mental state (Mini Mental State Examination, ≥21 required to participate). A short medical history was obtained to determine previous respiratory difficulties, swallowing difficulties, communication difficulties, brain injury, stroke, heart disease, and disorders/diseases.

To determine eligibility for the study in the recruited study group (healthy or COPD), bedside spirometry was performed on a calibrated Koko Spirometer to screen FEV_1/FVC (the forced expiratory volume in one second divided by the forced vital capacity). Healthy participants needed a ratio of >0.7 in order to be eligible, and COPD participants needed a ratio of <0.7 in order to be eligible. It is accepted that <0.7 is the threshold in differential determination of COPD using FEV_1/FVC (Global Initiative for Chronic Obstructive Lung Disease, 2015).

Equipment. This study used data collected by several pieces of equipment synchronized in PowerLab and analyzed using LabChart 7 (ADInstruments, Dunedin, New Zealand). Respiratory pattern was recorded using respiratory inductive plethysmography (RIP, Ambulatory Monitoring, Inc., Ardsley, NY, model 10.9000) – two elastic bands positioned around the participant's ribcage and abdomen that recorded movement during respiration. The ribcage and abdominal contributions to the participant's estimated lung volume were determined using simultaneous Universal Ventilation Meter (UVM) spirometry (Vacu-Med®, Ventura, CA). A piezoelectric accelerometer (Kistler Instrument Corporation, Amherst, NY, Model 8778A599) was placed on the participant's neck at the position of the thyroid notch at rest to record hyolaryngeal movement for marking swallowing events. A Glottal Enterprises (GE) PTL-1 oral pressure transducer and MS-110 data amplifier (Glottal Enterprises, Syracuse, NY) transduced intraoral air pressure changes during the swallow. A three-sensor manometer (Gaeltec CTO-3) recorded pressure changes in the oropharynx, hypopharynx, and upper esophageal sphincter.

Prior to participant arrival, all equipment was zeroed and a two-point calibration was completed. Known volumes of airflow/pressure were applied.

Procedure. After the consenting process was completed, the study began with fitting the RIP bands on the participant and donning a mesh retainer to hold the bands in place. Using the RIP and simultaneous spirometry, the participant performed three breathing tasks to determine the contribution of the ribcage to the abdomen. All three breathing tasks were performed while the participant wore a nose clip.

The breathing tasks. The first breathing task was two trials of 45 seconds of tidal breathing (Fig. 1). The participant was instructed to breathe quietly until told to stop. The second breathing task was swallow-like breathing (Fig. 2). Participants were instructed to breathe quietly until the investigator cued them to act as if they are about to swallow, hold their breath for a moment, and then resume breathing without completing a swallow. This task included five trials with at least 3-4 rest breaths between each trial. The investigator added more trials if the participant did not complete a trial correctly. The final breathing task was vital capacity maneuvers (Fig. 3). For this task, participants were told to breathe quietly until cued to take in a big breath until they could not take in more air, then exhale as deeply and as long as they could until they could not push out any more air.

In Figures 1, 2, and 3, the RIP signal is recorded in the first three channels (ribcage, abdomen, and sum, respectively). The last three channels show the data recorded from the

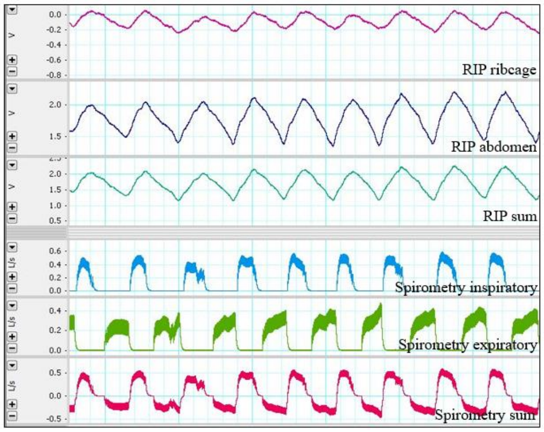


Figure 1. Tidal breathing task with simultaneous RIP and spirometry in LabChart.

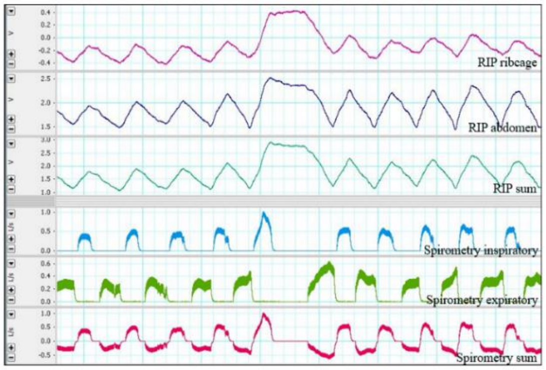


Figure 2. Swallow-like breathing task using simultaneous RIP and spirometry.

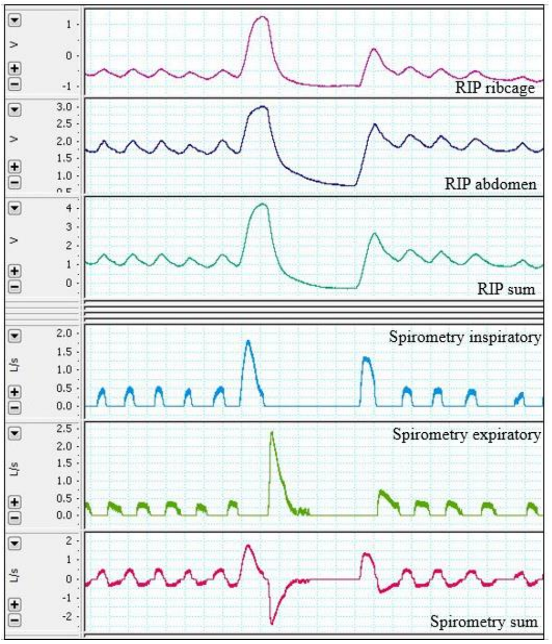


Figure 3. Vital capacity maneuver using simultaneous RIP and spirometry.

spirometer (inspiratory flow, expiratory flow, and sum flow, respectively).

Upon completion of the breathing tasks, an accelerometer was applied to the participant's neck at the thyroid notch and signal digitization confirmed proper placement. Then, the participant was prepared for the manometer insertion by applying Afrin spray into each nostril. After the Afrin set for a few minutes, the investigator lubricated the end of the manometer with E-Z Lubricating Jelly and inserted it into the nostril determined by the investigator and participant to be the most open. When the manometer reached the pharynx, the investigator gave the instruction for the participant to begin taking small sips of water and to begin digitizing. Using distance markers on the manometer and visualization of manometer signal in LabChart, the investigator positioned the manometer so that the three sensors were in the correct locations. The target placement was determined by sequential base of tongue (BOT) and hypopharynx signals and an M-wave recorded in the upper esophageal sphincter (UES) signal. The manometer was adhered to the nose and forehead of the participant to prevent movement during swallows.

The final piece of equipment – the flexible oral pressure tubing attached to the oral pressure transducer – was placed after the manometer insertion and before the swallow task. The tubing was positioned in the corner of one side of the participant's mouth and adhered to their cheek with medical tape to prevent expulsion from the mouth during the swallow tasks.

The swallowing tasks. The experimental task examined swallowing under four different lung volume conditions. These tasks utilized simultaneous RIP, accelerometry, manometry, and oral pressure transduction, as well as synchronized video capture. The participant self-administered 20cc water boluses at a specified lung condition when cued by the investigator. The participant was instructed to reach the requested place in their breathing cycle, hold their breath, put all the water into their mouth at once, and then swallow the whole bolus in one swallow before resuming breathing. Each lung volume condition task included seven bolus trials with at least 3-4 rest breaths between each trial. Additional trials were completed if coughing or speaking occurred during a trial, participant completed multiple swallows on a trial, or if the trial was not executed as directed. The study aimed for a minimum of five accurately executed swallows per lung volume condition.

The first lung volume condition was non-cued (NC). In NC, the participant was instructed to swallow whenever they were ready. The order of the subsequent three tasks was randomized using a counterbalance order. In the tidal volume (TV) swallowing tasks, participants were instructed to swallow at the top of an easy breath in. The resting expiratory level (REL) task was performed by the participant swallowing at the bottom of an easy breath out. In the total lung capacity (TLC) condition, the participant was instructed to swallow after taking a deep breath in.

Between each respiratory condition, the participants completed a Modified Borg Dyspnea Scale (MBDS), a visual analogue fatigue scale, and pulse oximetry. The MBDS rates shortness of breath or difficulty breathing on a scale of 0-10 from “nothing at all” to “maximal.” The fatigue scale rates how tired an individual is feeling on a scale of 0-10 from “nothing at all” to “worst possible fatigue.” Pulse oximetry measures the oxygen saturation level in the bloodstream, and should be above 94%. The participant was given rest breaks if they indicated that their difficulty breathing was greater than a three (“moderate”) on the MBDS, their fatigue was greater than a three (“mild-moderate”) on the subjective fatigue scale, or their pulse oximetry was below 90%.

Results

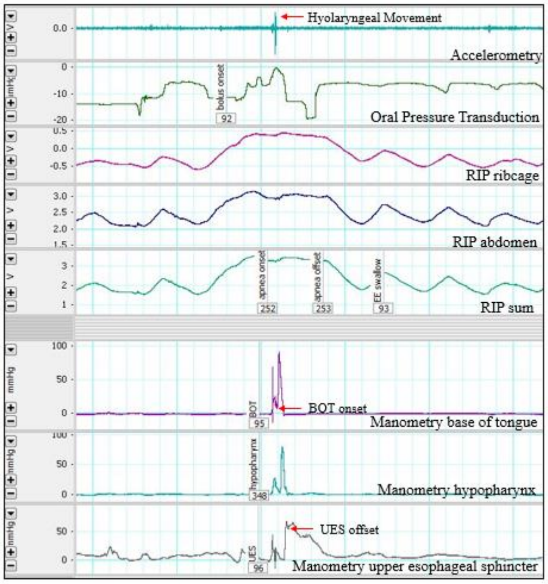


Figure 4. Data markings in LabChart 7 indicating hyolaryngeal movement, bolus onset, apnea onset and offset, respiratory-swallow patterning, BOT onset, and UES offset.

Data analysis. The lung volume at the time of swallow ("estimated lung volume," ELV) was calculated by simultaneous RIP and spirometry measurements. A MatLab script was utilized to determine the contribution of the ribcage to the abdomen, with the abdomen factor set as 1. Expiratory reserve volume (ERV) was computed for each participant based on spirometer signal during the vital capacity maneuver trials. For each bolus trial, the ELV was computed using the equation:

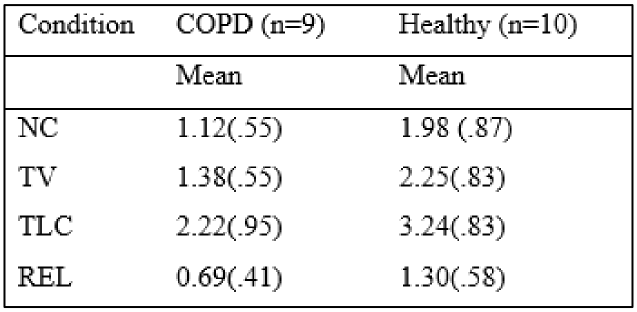
$$ELV = RC(x) + AB(1) + ERV.$$

Pharyngeal swallow duration was determined by calculating the time between the onset of base of tongue pressure increase and offset of upper esophageal pressure. Respiratory-swallow patterning – determination of inspiration or expiration pre- and post-swallow – was determined from the RIP signal.

Participant demographics. The participant pool used for the principal investigator's dissertation included ten healthy participants (7 female, 3 male) and nine COPD participants (3 female, 6 male). The mean age of the healthy participants was 59.40 years (range: 50-77), and the mean age of the COPD participants was 71.99 years (range: 61-83).

Means and statistics.

Estimated lung volumes. The estimated lung volume at the time of swallow was calculated for both healthy and COPD participants across all four lung volume conditions. A mixed ANOVA was used. The interaction was not significant, however, main effects for group and lung condition were significant. Specifically, this showed that participants with COPD swallow at a significantly lower estimated lung volume than older healthy.



Condition	COPD (n=9)	Healthy (n=10)
	Mean	Mean
NC	1.12(.55)	1.98 (.87)
TV	1.38(.55)	2.25(.83)
TLC	2.22(.95)	3.24(.83)
REL	0.69(.41)	1.30(.58)

Table 1. Estimated lung volume means (SD) in liters across lung volume conditions in healthy and COPD participants.

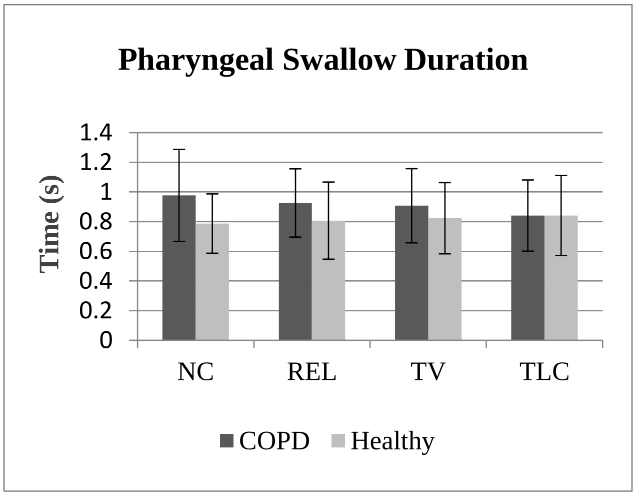


Figure 5. Pharyngeal swallow duration means in seconds across lung volume conditions in healthy and COPD participants.

Pharyngeal duration. Pearson's correlation revealed that a significant inverse relationship was present between estimated lung volume at the time of the swallow and pharyngeal swallow duration in individuals with COPD. A mixed ANOVA determined that the duration of the pharyngeal phase of swallowing was not significantly longer in COPD participants compared to older healthy. However, the COPD pharyngeal swallow duration approximated the healthy pharyngeal swallow duration at the total lung capacity lung condition.

Respiratory-swallow patterning. COPD resumption of breathing in either inspiratory or expiratory across lung volume conditions was analyzed. A repeated measures ANOVA showed a significant difference in resumption of respiration on inspiration across lung volume conditions in individuals with COPD. Specifically, resumption of breathing in inspiration after the swallow occurred significantly less often in the higher volumes, TLC and TV, than in the lowest, REL.

Conclusion

This study demonstrated that individuals with COPD swallow at a lower lung volume than older healthy individuals. This can be attributed to how COPD changes the anatomy and physiology of the respiratory system. Due to bronchoconstriction and air trapping, individuals with COPD cannot take in as much air into their lungs as healthy individuals. Therefore, the lung volume capacities of individuals with COPD are lower than that of healthy individuals, which alters the lung volume at the time of the swallow.

Furthermore, this study also found that there is an inverse correlation between the lung volume at the time of the swallow and pharyngeal swallow duration in individuals with COPD. This indicates that swallowing at lower lung volumes extends the duration of the pharyngeal swallow. However, at total lung capacity, individuals with COPD averaged the same pharyngeal swallow duration as the older healthy individuals, demonstrating that swallowing at higher lung capacities approximates normal pharyngeal swallow duration.

Finally, this study demonstrated that individuals with COPD are less likely to follow a swallow with inspiration when swallowing at a higher lung capacity. When compared to REL and NC, swallows at TLC were followed significantly more by expiration in individuals with COPD. This suggests that increasing lung volume at the time of swallow puts COPD individuals in a more ideal respiratory-swallow patterning that follows the swallow with expiration, approximating the respiratory-swallow patterning of healthy individuals.

In conclusion, a future direction for this line of research is to continue to investigate the application of purposefully altering respiratory-swallowing patterning by increasing lung volume prior to swallowing in order to approximate the lung volume at the time of swallow in healthy individuals, normalize pharyngeal swallow duration, and target exhale-swallow-exhale respiratory-swallow patterning. Future work will determine if this practice will decrease the risk of penetration or aspiration in an already-compromised system.

Personal Reflection

The experience of being a research assistant and writing an undergraduate thesis taught me a lot about the field of Speech-Language Pathology and myself. This experience made me step out of my comfort zone and challenged me in new ways.

I'm so thankful that I had an opportunity to assist Teresa Drulia with her research. I joined her research team in the last year of her dissertation, so I had a lot to learn in a short amount of time about the nature of her research, the methods and procedure of her study, and the tasks that were assigned to me. Jumping onto her team taught me that I am a fast learner and that I pick up new skills quickly. When I first started marking data, it would take me several hours just to mark the number of the swallow, the bolus onset, and the respiratory patterning for a given participant. By the end of our time in the data marking stage, I was able to accurately mark seven data points per swallow for an entire file in just a few hours. When the other research assistant, Rebecca, and I first started assisting on study days, Teresa had to walk us through all of the steps of the calibration process and the procedure of the study. Both Rebecca and I learned very quickly what needed to be done and in what order, and we developed an efficient pattern of completing calibration with little assistance from the principal investigator and a comfort with the procedure of the study; it became second nature.

One of the foundational principles of Speech-Language Pathology is evidence-based practice. The fruit of research has valuable clinical implications, and all clinical decisions should be based on the best practices determined by thorough research. Through building a relationship with Teresa and discussing her dissertation and her career as an SLP in a clinical setting, I learned that while research is important to the field of Speech-Language Pathology, it is not for everyone. Teresa told me that she was thankful for her years as a clinical SLP before returning to school to get her Ph.D. She spoke of her difficulty in learning how to do research after working as a clinician for so many years, but how she has a big heart for learning everything she can about the mechanism for dysphagia in individuals with COPD. Teresa has family members who have COPD and has seen the impact of swallowing difficulties in their lives, and that drives her to keep learning through research, even though it is not something that came easily to her at first. I now have a lot of respect for SLPs who dedicate their careers to researching specific topics in our field and sacrifice working in a clinical setting to increase the body of research and improve the care for specific populations. I have learned that doing research is not just a one-time decision to write a dissertation to get a degree; it is a work of heart and requires caring deeply about the work you are doing and the population it impacts.

While writing the deliverable thesis, I learned a lot about academic writing. I had the opportunity to read textbooks written by the best of the best in the field, search for relevant journal articles on the JMU library server, synthesize the information from these sources, and write a literature review. The hardest part of this process was putting words on blank paper. High school and college literature classes taught me how to write final drafts in the first sitting, and writing a big paper that would require months of edits scared me. Additionally, I felt the expectation to know everything there is to know about swallowing and COPD. My mentor, Erin Clinard, assured me that I was not expected to be an expert in the field nor write like one. When I thought my literature review had to sound like a textbook, my thesis adviser, Dr. Erin Kamarunas, told me that some of the best academic writing is the kind in which the author writes with their own personal voice. When I got my first rough draft back from my readers, it was strangely encouraging to see all of the edits that were suggested. After that point, my fear of writing was gone, because I knew that my readers would help me improve upon what I had already written, not shame me for not being perfect on my first try.

Above all these things, my experience as a research assistant and writing an undergraduate thesis taught me that Speech-Language Pathology – and more specifically, swallowing therapy in older adults – is the career I want to pursue. I have known that I wanted to work as an SLP in a healthcare setting since 2010, but this experience solidified that desire. I never really had a desire to conduct research before joining Teresa’s team, but I knew that if I was going to go back for a Ph.D. in Communication Sciences and Disorders, I wanted it to be after I spent a significant amount of time in a clinical setting. I look forward to working in a clinical setting for some time and finding a niche – the passion that Teresa has – for myself, and possibly pursuing research later in my career.

In conclusion, writing an undergraduate thesis taught me that I do not have to be afraid of the process of writing and that being a Speech-Language Pathologist means you never stop learning. Being a research assistant taught me that research is a fulfilling calling and something that I could confidently do in pursuit of a doctorate. I am so thankful for this experience, the people it brought into my life, and the people who came alongside me to support me through it. There were times when I felt like it would be easier to give up, but my advisers, readers, mentors, and peers came alongside me, encouraged me, and assured me that I am capable of so much more than I think I am and that it would be worth it. It wasn’t always easy, but I am glad I did it.

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