The Effects of a Volitional Breathing Technique on Swallowing and Respiratory Coordination in Individuals with Amyotrophic Lateral Sclerosis: A Procedural Protocol

Tassani Hoskyn, Jillian Ross, Ahila Thayaparan

Supervisor: Stuart Cleary; Reader: Tammy Hopper

Volitional Breathing Technique Effects on Swallowing

ABSTRACT

Amyotrophic lateral sclerosis (ALS), commonly referred to as Lou Gehrig's disease, is a common motor neuron disorder resulting in the deterioration, weakness and eventual atrophy of many of the key muscles of the body required to sustain life. Breathing and swallowing problems are common among people with ALS (PALS). This current research paper is part of an ongoing study and builds upon a pilot study completed in 2011. The pilot study examined the effectiveness of a new behavioural swallowing technique, referred to as the 'barrel chest' maneuver. This is a simple strategy that can be taught by healthcare professionals to PALS and requires the patient to swallow after a large inhalation, creating a 'big barrel chest' full of air. Employing the 'barrel chest' maneuver is hypothesised to increase lung volume and generate a more forceful cough should material penetrate the airway. The strength of coughing is dependent on lung volume, i.e., a higher lung volume provides a stronger cough. The current SPA 900 project involves analyzing a new dependent variable, i.e., lung volume percentage at the onset of swallowing. A new lab protocol was developed and incorporated into an ongoing study aimed at examining the effectiveness of this compensatory safe swallowing technique.

INTRODUCTION

Amyotrophic lateral sclerosis (ALS), commonly referred to as Lou Gehrig's disease, is one of the most common motor neuron disorders and is characterized by a rapid accrual of disability. This disease involves the progressive deterioration of the motor neuron pathways and the wasting and eventual atrophy of the muscles as the pathways are disconnected from the central nervous system (Miller et al., 1999, 2009). There are two subtypes of ALS based on the site of onset: bulbar and limb. Bulbar ALS indicates that the condition began at the level of the brainstem. Individuals with this variant experience difficulties with speech and swallowing relatively early in the course of the disease as the majority of motor control for these functions occurs at the level of the brainstem. In general, people with ALS (PALS) with the limb onset variant experience these difficulties later in the progression of the disease (Mitsumoto, 1994). Life expectancy is between 3-5 years following diagnosis of either variant. ALS affects approximately 3,000 people in Canada and has an incidence rate of 0.6-3.3/100,000 people worldwide. ALS is age-related and onset is typically between 50-60 years of age (Strong, 2004).

Breathing and swallowing difficulties are prevalent amongst PALS and significantly impact their health and well-being. The deterioration of the cortical pathways to the brainstem in bulbar onset ALS causes disruptions in the coordinated movements involved in speech and swallowing. Although PALS with the limb onset variant do not initially experience these same difficulties, these same pathways will ultimately be attacked. Regardless of the site of onset, both forms of ALS will eventually result in breathing and swallowing problems. Individuals with respiratory insufficiency often demonstrate an aberrant pattern of inhaling after swallowing, which may lead to complication associated with aspiration and airway obstructions.

The 'Barrel Chest' Maneuver

Research has shown that a variety of rehabilitative techniques may help to promote swallowing function and manage the symptoms associated with respiratory failure (Miller et al., 1999, 2009). Promoting a more normal pattern of breathing and swallowing integration may help PALS to better protect their airway when swallowing and therefore experience less psychological distress while eating. Improving knowledge and understanding of the respiratory patterns of healthy swallows and the laryngeal cough reflex has helped health care professionals provide PALS and their families with strategies to ensure a safer swallow. One such proposed strategy is the expanded chest posture or 'barrel chest' maneuver. This simple, easy-to-teach technique may provide this population with a healthier swallow. The 'barrel chest' technique involves teaching PALS to assume an exaggerated breath posture just before swallowing to increase the volume of air in their lungs during their swallow. A high lung volume is important for the laryngeal cough reflex, which is designed to protect the airway from foreign materials. Cranial nerve receptors in the larynx and trachea detect foreign material that penetrates the airway. If foreign material is detected, the laryngeal cough reflex is initiated and continues until the material is expelled from the airway. Coughing is volume dependent, in that the strength of the cough is dependent on the amount of pressure created by the pre-cough lung volumes. Conversely, lungs with a smaller amount of air will elicit a weaker cough and therefore may make it more difficult to clear the airway. The 'barrel chest' technique encourages patients to breathe in deeply and then swallow with a large amount of air in the lungs to ensure a more forceful cough should they aspirate. This expanded chest posture during feeding activities increases lung volume and thus increases the pressure available should the laryngeal cough reflex be elicited (Murray, 1999).

The respiratory phase (percentage or point within a respiratory cycle or pattern in which a swallow occurs) also has an impact on the protective ability of coughing. A healthy swallow occurs during the expiratory portion of a respiratory cycle. The most common pattern is to begin exhaling, swallow, and then continue exhaling after the swallow is complete. During a swallow, respiration ceases and the airway is closed by a protective reflex referred to as swallowing apnea. An aberrant pattern exists when a person inhales immediately following a swallow. This is potentially dangerous as food may accumulate at the base of the tongue or pyriform sinuses after the swallow and as the airway opens, foreign material that has pocketed in either of these structures may be drawn in, leading to aspiration and/or airway obstruction. For PALS, the chances of having material remaining after the swallow are increased as the musculature of these intrinsic structures may be weakened and swallowing becomes slow and inefficient (Mitsumoto, 1994). This similarly increases the chance of aspiration and aspiration pneumonia, a potentially deadly condition in PALS.

In addition to the protective cough reflex, a volitional cough may be elicited to clear any material remaining within the airway after swallowing. In volitional coughing, initially the glottis closes, causing pressure to build beneath the glottis. Then a sudden opening of the true vocal folds leads to the release of the built-up air propelling foreign materials up and out of the airway (Murray, 1999). Healthy individuals are generally able to utilize a volitional cough to successfully clear their airway; however, persons with compromised musculature find it more difficult to elicit a strong cough due to muscle weakness. The limited or absent volitional cough present in PALS supports the notion of teaching protective maneuvers in order to minimize or avoid aspiration.

The purpose of the ongoing research project is to determine if the ‘barrel chest’ maneuver promotes a safer and more effective pattern of breathing and swallowing integration when the technique is employed by PALS to prevent aspiration during mealtime. This benefits the patient as they can proactively prevent aspiration and pneumonia, which also results in decreased medical costs. Additionally, this technique may give PALS a level of comfort and greater independence, increasing their mealtime related quality of life.

Purpose

As concerns around nutrition, swallowing and the dangers of aspiration have a significant impact on the daily life of PALS, the goal of this postural breathing technique is to increase airway protection and clearance capabilities for patients while swallowing. This SPA 900 project is an extension of a larger ongoing study of airway clearance in the ALS population and builds upon a recently completed pilot study. In the initial pilot project, data was collected from ten PALS coached in a volitional breathing technique developed to facilitate cough effectiveness and, consequently, airway clearance success and increased safety in swallowing (Bohaichuk, 2012). Through maintaining a ‘barrel chest’ posture before swallowing, the use of the accessory muscles of inspiration was increased with the goal of expanding lung volume and expiratory breathing after swallowing. The focus for the original Master’s research paper was to evaluate the effectiveness of the ‘barrel chest’ technique on increasing expiratory breathing after completing a swallow as well as altering patient perceptions regarding their concerns with swallowing. Preliminary findings of the pilot project revealed a statistically significant increase in the average number of typical breathing patterns while swallowing (exhalation before and after the swallow) following training and participants made positive qualitative comments on the usefulness of the technique (Bohaichuk, 2012).

When developing evidence for new therapeutic techniques, it is crucial to establish the internal validity of the research design and the methods used in data collection and analysis. The inter-rater reliability or the consistency of responses made by individual observers using the same definitions and classification is an important aspect of maintaining strong internal validity. This can be determined through calculating the extent to which independent observers agree when examining the same information using the same operational definitions, collection and classification methods. Developing specific, consistent protocols for considering data is a necessary step in analysis to support later analyses and conclusions drawn from the data (Bailey & Burch, 2002).

The purpose of this SPA 900 project was to further data collection following the protocol used in the previous study and to extend the pilot study (Bohaichuk, 2012) by developing a new inter-rater reliability protocol for the new dependent variable, i.e., the percentage of lung volume at the point of swallowing. The previous protocol used in this study had utilized basic visual inspection of the data to conclude findings. The goal of this current research project was to build upon the visual analysis method to create a more fine-tuned, systematic method of analysis. This process included multiple steps and drafts of a protocol and operational definitions for different aspects of the data. Novel data had been collected from three additional participants since the first portion of the study. An additional goal was to test the level of inter-rater reliability using this new protocol.

Research Questions

From the existing literature, several research questions were proposed. These included:

1. Does an expanded chest posture prior to swallowing promote increased lung volumes as PALS swallow? More specifically, does the technique promote a more favorable percent within a respiratory phase where a swallow is initiated when using the technique?

2. Can two independent judges achieve an acceptable rate of reliability when analysing blinded data using a protocol developed specifically for the purposes of this study?

METHODS

Participants

All potential participants for the original study were recruited through the *Misericordia Hospital* and the *University of Alberta (U of A) Hospital's ALS Clinic*. The three new participants were recruited solely through the *U of A Hospital's ALS Clinic* bringing the total number of participants to 13. In order to be participants in this study, strict inclusion criteria had to be met (see Bohaichuk, 2012 for inclusion criteria and demographic information).

A final sample of 8 participants was used in the Master's thesis on which this current study is based. Information from two participants was excluded from this larger study due to instrumentation limitations, which restricted the amount of meaningful data that could be collected. However, data from these participants were included when developing the analysis protocol of the current study in an attempt to show a benefit from the technique utilizing the new procedural analysis.

Using the previously established inclusion criteria, data was gathered from an additional three participants from the *U of A Hospital's ALS Clinic* in 2012. The age of these two men and one woman ranged from 22 to 82 years (median age = 70 years, range = 60 years). Two presented with a limb onset form of ALS and the final participant (participant YN) was additionally diagnosed with an upper motor variant motor neuron disorder. It is important to note that this participant also experienced a left cerebrovascular accident (CVA) on February 9, 2012 which may have complicated interpretation of the results for this participant. The average time post onset for these three participants was 36 months (ranging from 5 to 45 months).

Materials

The equipment used to gather data on participants' respiratory cycles while completing a swallow included a *Vernier* 3-Axis Accelerometer (model # 3D-BTA), a *Vernier Lab Pro* transducer, a *Vernier* Respiration Monitor Belt (model # RMB), a *Vernier* Gas Pressure Sensor (model # GPS-BTA) and *Logger Pro 3* Data Collection Software. Using an accelerator is a non-invasive way to measure vibration and acceleration across the X (horizontal), Y (vertical) and Z (angled) planes (*Vernier* User Guide, 2006). Placing the accelerometer at the position of the thyroid cartilage allows for the detection of the anterior (X plane) and superior (Y plane) movements of the hyolaryngeal complex at the onset of a swallow. In this study, the *Vernier* 3-Axis Accelerometer and *Vernier Lab Pro* transducer were used to measure hyolaryngeal movement. Past research indicates that although there are multiple methods that can be used to measure swallowing and hyolaryngeal movement, thyroid notch elevation is a meaningful and efficient measure of the onset of the pharyngeal stage of swallowing (Bech-Hansen Zoratto, 2009). As material is moved further back in the oral cavity, cranial nerve innervation causes the hyolaryngeal complex, consisting of the hyoid bone and the structures of the larynx, to be elevated and pulled forward. This movement is referred to as the pharyngeal stage of swallowing and ensures that the epiglottis folds over the airway, closing the opening and moving the larynx out of the pathway of material being swallowed (McCullough, 2000). Therefore, hyolaryngeal movement signifies the movement of the hyolaryngeal complex and suggests the occurrence of a swallow. Although neither the size of the bolus nor the amount of residual material in the base of tongue or pyriform sinuses can be established through examination of thyroid notch elevation, this movement can be marked as a swallow occurrence (Murray, 1999). There are several alternative methods to measure this movement including cervical auscultation, contact microphones, submental electromyography, or videofluoroscopy. However, of these, an accelerometer is non-invasive, results in no exposure to radiation, it is generally cost effective, portable and a relatively simple and reliable means of measurement (Bohaichuk, 2012).

A *Vernier* Respiration Monitor Belt and *Vernier* Gas Pressure Sensor GPS-BTA were used to measure participant respiration rates and cycles in conjunction with a *Vernier Lab Pro* transducer. A kinematic measure of pressure changes caused by chest wall movement was also gathered using a nylon chest strap. *Vernier Lab Pro* software was used to interface both with the respiration belt and with the accelerometer. Information on respiratory phase (inspiration and expiration) and laryngeal elevation (swallows) was displayed simultaneously across time using *Logger Pro 3* data collection software. Equipment was sterilized between uses with standard techniques, e.g., *Metriguard* spray and alcohol swabs.

Research Design

A One-Group Pretest-Posttest Design (within-subjects pre-post experimental research design) was used in the pilot project to investigate the effects of instruction of the 'barrel chest' maneuver on swallowing and its percentage within a respiratory phase for patients with ALS. The dependent variable was identified as the percentage of time within a respiratory cycle when the swallow occurred. A total of 13 participants were studied, i.e., 10 from the previous study and 3 new participants.

Procedure

For each participant, the data collection session consisted of a baseline measure, treatment and post-treatment trials (see Bohaichuk, 2012 for complete experimental protocol). During the baseline phase, information on participants' respiratory patterns during swallowing and their subjective impressions of swallowing were gathered. All participants began by eating a minimum of 10 swallows of pudding and completed a short survey that included questions from the *Mental Health* subsection as well as four questions from the *Symptom Frequency* subsection of the *SWAL-QOL*. Then the respiration monitor belt was placed around the participant's chest and data was collected for 30 seconds of tidal breathing to determine if sufficient pressure, i.e., distinct peaks and troughs of pressure change, had been obtained. The accelerometer was then held in position lateral to the thyroid prominence, i.e., thyroid notch, and the participant was presented 20 millilitres (ml) of tepid water. The bolus volume size was chosen as it approximates the 'typical' size bolus for healthy adults, which ranges from 16 to 26 ml (Adnerhill, Ekberg, & Groher, 1989). To determine a participant's baseline respiratory pattern, data was collected for ten swallows of the 20 ml bolus volume. For each swallow, the pattern of breathing following each apneic period was recorded. The apneic periods occurred as the air pressure stalled due to the closure of the airway.

During the treatment phase, the participant was seated in a chair modified to maintain a 90-degree posture during the swallowing tasks. The patient was instructed to use the 'barrel chest' posture just before swallowing. The technique was modeled for the participant three times during dry swallows.

Following an explanation of the technique, the participant was instructed to sit in an upright position and drink 20 ml of water. While holding the bolus in their mouth, participants were cued to take a deep breath and hold it before swallowing. Participants practiced the technique with verbal and physical prompts as needed during two swallows with water and three dry swallows. If the participant was unable to perform the technique after 10 attempts, data collection was discontinued.

Once the participant understood the technique and had a brief rest, 10 liquid swallows using the 'barrel chest' technique were completed. The participant was prompted to take a deep breath before swallowing and to maintain the expanded chest posture during the swallow. The accelerometer was held in position throughout the swallow by the researcher and the pattern of breathing was recorded. Respiration following the swallow was noted as either inspiratory or expiratory. The participant was then asked to eat a small amount of pudding (a minimum of 10 swallows) using the same technique and answer questions from the *Mental Health* and *Symptom Frequency* subsections of the *SWAL-QOL*, followed by five qualitative interview questions. The participant continued to sit in the modified chair throughout the treatment swallows.

Developing the protocol

In order to develop a reliable protocol, multiple steps and revisions were undertaken. Initially, one student researcher was trained in the existing data analysis protocol. Following this training, the researcher developed a protocol consisting of a refined set of operational definitions to more accurately determine the percentage of time within a respiratory cycle when the swallow occurred. Afterwards, two additional student researchers were trained in the use of the *Logger Pro 3* software by the first researcher using the initial draft of the data analysis protocol. This exercise reviewed the effectiveness of the initial draft in explaining the multiple steps required to analyze the data.

To determine points where swallows occurred, a clear operational definition was required. As a group of three, the researchers edited the preliminary draft and decided that a swallow occurred where a peak existed in the accelerometer data. This peak represents the elevated movement of the thyroid notch. Once these peaks were determined, the corresponding point on the respiratory data had to be marked. This point helped to determine where the participant was in terms of their respiratory phase. Following the visual inspection, this peak section on the accelerometer data was highlighted and the numerical data in the table was reviewed. Flat sections in respiratory pattern were operationally defined as apneic periods, i.e., the specific onset of the pharyngeal stage of swallowing. As the airway is closed during a swallow, a change in pressure is not expected. The group decided that a minimum of .06 seconds (s) of static pressure was sufficient to consider it as an apneic period during which a swallow occurred. At this point, the preliminary draft was modified and included additional details to guide in consistent and reliable data analysis. Following these revisions, an initial trial of the effectiveness of the protocol was undertaken. Individually, each researcher inspected the same three randomly chosen files and noted the data of interest: the type of respiratory phase, the initial and final times of the respiratory phases, and the initial time of swallow. The data was compared and any data that did not match was re-examined as a group to determine where and why the element of confusion existed. Additional decisions and definitions were then developed to aid in the consistent analysis of the data and decision making regarding visual inspection. Once the group established a consistent method of analysis and an acceptable criterion of inter-rater reliability was achieved, the data from all 13 participants was analyzed.

Measures of reliability were calculated for determining the initial time of swallow and where within the respiratory cycle, measured as a percentage, the swallow occurred. If at least one of the three researchers encountered an area of ambiguity where the pressure graph could be interpreted in more than one way, a group meeting was held and revisions were made to the protocol. The researchers then re-examined all previously completed data analyses to make sure that these new modifications were accounted for. For example, there was occasional confusion over which of two peaks represented the maximal point of inspiration. The examiners as a group decided that if the inspiration was accompanied by a minimum of 0.2 kilopascals (kPa) change in pressure, it would be examined as a separate respiratory phase (inspiration and expiration). If the pressure associated with inspiration was less than 0.2 kilopascals (kPa), the whole inspiratory section was taken to represent one inspiratory phase (inspiration only). All previous data was adjusted to represent this change in protocol.

RESULTS

One of the primary research questions of this study was determining the level of inter-rater reliability that could be achieved by two independent judges when using a newly developed protocol to analyze hyolaryngeal movement and respiratory pressure data. Following the initial analysis of all participant data, one student blinded 30% of the data and provided it to the other two researchers to independently examine using the newly developed protocol. Each of these researchers was provided with a password-protected *Excel* file to input their data. The blinded data was then compared to determine rates of inter-rater reliability. Although the inter-rater reliability was low for both initial and final times of the respiratory phases, 84% agreement was reached for type of respiratory phase and 87% for initial time of swallow.

The presence of low reliability measures for the respiratory phase start and end times led researchers to implement a forced-choice analysis. Forced-choice is a type of analysis that can reduce ambiguity for observers as it decreases the amount of potential responses for an event. This method also helps assure reliability and provides ideas for future procedural modifications as two researchers must explore differing interpretations and come to the same conclusion for each piece of data (Bailey & Burch, 2002). For this study, this entailed that two researchers analysed the data from all 13 participants together in order to reach mutual decisions. A new *Excel* file was created for the new findings and the percent within the respiratory phase at which a swallow occurred was determined for each swallow.

The slightly lower reliability for type of respiratory phase (84%) may be accounted for by the ambiguity concerning the *in-ex* and *ex-in* respiratory phase patterns. At times, the pressure data did not contain an easily identifiable peak or trough and instead consisted of a plateau in areas of maximal inspiration or expiration. When this occurred, some interpretation was required on the part of the researchers in deciding how to classify the respiratory phase. For example, when the swallow occurred on the plateau representing the peak, the respiratory phase could be interpreted as *in-in*, *ex-ex* or *in-ex*. The low reliability related to the initial and final times of swallow often occurred when the swallow occurred very close to the peak or trough. When the swallow took place a few milliseconds before or after the peak or trough, there was high variability in interpretation. A swallow occurring extremely close to the trough could be classified as *ex-ex*, *in-in*, or *ex-in* depending on how the researcher interpreted the data.

Further modifications to the protocol were made after the initial analysis to limit variability in data interpretation. The *ex-in* and *in-ex* respiratory pattern classifications were eliminated leading researchers to choose from two patterns (*ex-ex* or *in-in*) instead of four. This was done for three reasons; firstly, to increase reliability measures since researchers would now be choosing between two more clearly defined categories instead of four. Secondly, increased reliability at the present stage of this research project would allow for better reliability measures for future studies based on this protocol. Finally, an additional area of study that was not specifically examined in this paper was whether the ‘barrel chest’ procedure leads to a more favourable swallowing pattern (*ex-ex*). This can be examined using two categories, a favourable pattern (expiring post swallow) and a non-favourable pattern (inspiring post swallow). Therefore, it is not a necessary to have four patterns. Since the presence of these two additional patterns do not contribute to a meaningful interpretation of the data, they were excluded. The data contained within this paper are based on the *in-in* and *ex-ex* respiratory patterns.

The second research question in this study was whether instruction and use of the expanded 'barrel chest' posture by PALS could promote swallowing at an earlier point, i.e., lower percentage, of their respiratory phase, thus increasing the lung volume available during swallowing. As this project is part of a larger study, inferential statistical analyses will be completed when the entirety of the data has been gathered. However, descriptive techniques indicated a trend towards participants swallowing earlier in the respiratory phase after being taught the expanded chest technique. In Figure 1, a trend toward swallows occurring earlier within a respiratory phase, i.e., a reduced percentage, was observed in 9 of 13 participants. With instruction of the 'barrel chest' maneuver, the majority of participants in this study had increased the lung volume. This is important for the laryngeal cough reflex in the event of aspiration.

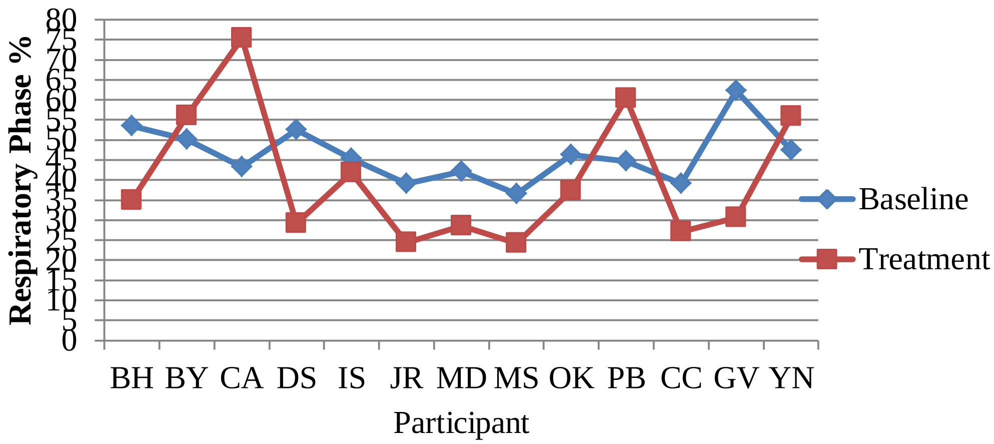

Figure 1. Mean respiratory phase (%) at the time of swallow across participants with and without utilizing the 'barrel chest' posture.

Similarly, the mean percent respiratory phase at the time of swallow for all swallows across all participants at baseline was approximately 46%, whereas in the treatment phase the mean percent respiratory phase at the time of swallow was approximately 40%. This demonstrates that through instruction of the 'barrel chest' technique, patients were swallowing at an earlier point in the respiratory phase and had more air pressure available should they aspirate.

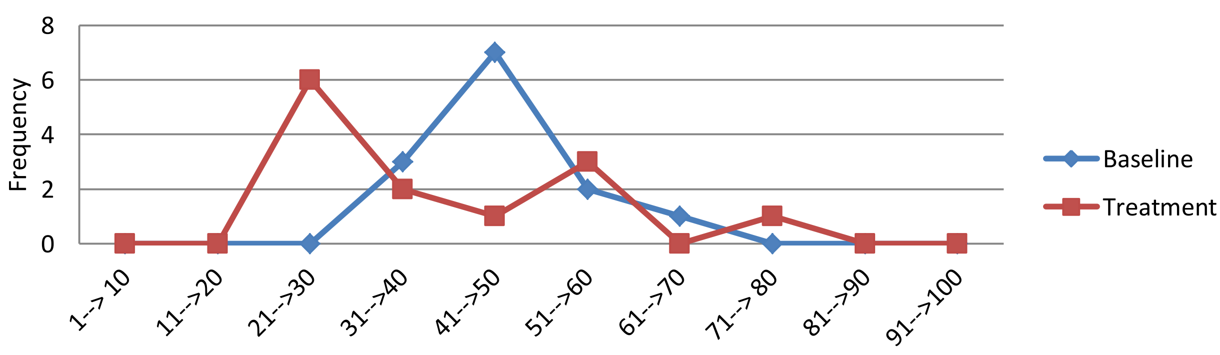

Figure 2. Frequency of respiratory phase (%) interval at the time of swallow across participants with and without utilizing the 'barrel chest' posture.

All of these findings would suggest that the expanded ‘barrel chest’ posture may have a beneficial effect on the time at which a swallow occurs in a respiratory period, increasing the amount of air left in the lungs during the swallow, and thus increasing air pressure available for coughing after a swallow in the event of aspiration.

DISCUSSION

In this study, patients with ALS were taught to employ a ‘barrel chest’ posture designed to increase lung volume and promote safer swallowing. Data from 13 PALS was examined to determine the effect of this technique on where within a respiratory phase a swallow occurs. When a swallow occurs earlier (or after a lower percentage of the phase has been completed), there are higher levels of air volume and pressure remaining in the lungs during and after the swallow is completed, which could potentially be used to expel aspirated material. Through descriptive analyses, general trends towards increased lung volumes at the time of swallow were seen in participants after they were taught the ‘barrel chest’ technique. The average respiratory phase percentage for the majority (9/13) of participants was reduced after learning the technique as compared with baseline measures. Similarly, the average respiratory phase percentage for all participants after treatment was lower (40%) as compared with the average point of the respiratory phase in which swallows occurred during the baseline measure (46%). These findings suggest that with appropriate instruction, the expanded ‘barrel chest’ technique could promote swallowing earlier in a respiratory phase for PALS, thus increasing the amount of air volume and pressure available in case of aspiration.

Reliability of the New Protocol

A new protocol was developed to analyze the respiratory data with the goal of establishing a reliable and consistent method of classifying and analyzing hyolaryngeal elevation and respiratory pressure data. The researchers were able to obtain high measurements of reliability for the initial time of swallow (87%) indicating that the protocol was fine-tuned enough that the researchers were able to reach the same conclusion the majority of the time.

Future Research

As a secondary procedure, researchers attempted to calculate the percentage of forced vital capacity (FVC) using the chest strap data. FVC is represented by the amount of air in the lungs after a maximal task, i.e., the maximum inhaled and maximum exhaled air. A change in percentage can be calculated by comparing the lung volume attained during tidal breathing and maximal breathing tasks. The researchers attempted to compare this FVC data to the data collected during the tidal breathing task, which requires approximately 40% of the FVC. FVC is important to PALS as higher percentages of FVC equate to more air and therefore a higher pre-cough volume (PCV) at a patient’s disposal should they aspirate. A positive treatment effect would likely enhance FVC volumes, which in turn translates into a higher PCV.

The goal had been to compare the percentage of the dependent variable calculated within the respiratory limb where the swallow occurred between the tidal breathing (baseline) and the ‘barrel chest’ (treatment) data. However, due to the apparent shifts in pressure changes between trials as seen from the variances in the chest strap data, a static comparison could not be completed. The chest strap data in terms of pressure readings (kPa) had shifted.

This may have been the result of two factors. Firstly, this may be an artifact of the strap shifting position following the maximum shift in chest wall excursion resulting in less pressure on the patient's chest. In other cases, the chest strap was removed between trials. Therefore, it has been concluded that the chest strap data could not be reliably used to calculate FVC.

One future modification that may help increase reliability measures would involve leaving the *Vernier* Respiration Monitor Belt on the participant during the entire length of data collection. The repositioning of the belt strap between pre- and post-treatment trials affected the ability to reliably interpret the data. This study was designed to measure lung pressure changes rather than lung volume changes. In future trials, the FVC and swallow tasks could be completed during the same trial to avoid pressure differences and allow for a more consistent comparison, e.g., a FVC task, followed by the swallow task, completed consecutively. Employing this modification in future studies would allow for a more accurate comparison of lung volume changes during tidal breathing and maximal breathing tasks employing the 'barrel chest' procedure. Another potential measure for this dependent variable could be to use a 1-liter syringe to help quantify the degree to which the chest wall movements equate to changes in lung volume. Using a syringe would provide a standard metric by which to estimate the percentage of FVC at the time of the swallow.

A second possible avenue for future research may be to use spirometer data, specifically the flow rate (L/s) instead of the chest wall excursion data, simultaneously during the swallow. A dry swallow using a spirometer was attempted in the lab with an open-mouth posture created by maintaining a lip seal on the mouth piece attached to the spirometer. It was determined that this was a challenging and difficult task. Therefore, an option to trial in the future would be to use a specially equipped face mask coupled with the spirometer to allow patients to maintain a more natural lip posture.

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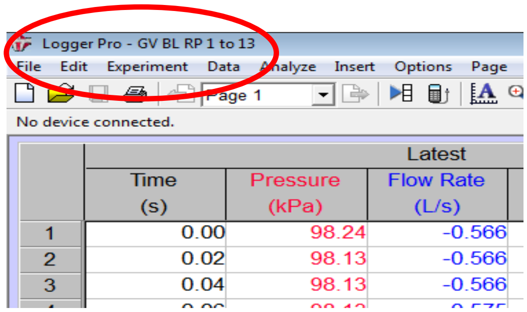
Appendix A

Procedural protocol:

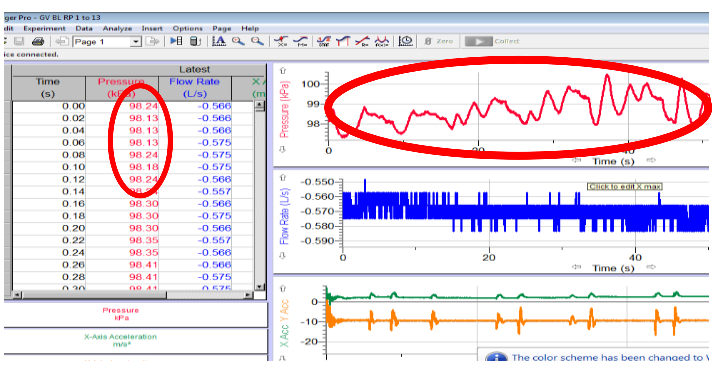
1. Opening the file



Participant data was saved using *Logger Pro 3* software. The file names begin with the participants' initials followed by a code indicating the condition. The number of swallows is then indicated after the condition. For example, 'GVBLRP1-13' would be participant GV's respiratory phase data in the baseline condition where 13 swallows were completed.

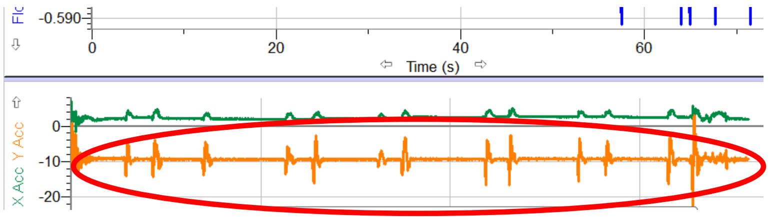
BL	Baseline Condition	TX	Treatment Condition	RP	Respiratory Phase

2. Initial Visual Inspection



Swallow apneic periods are identified as points where the participant experienced stalls in pressure indicating a swallow. Apneic periods are visually inspected by reviewing both the respiratory and the accelerometer data simultaneously, using the *Logger Pro 3* software. The top graph indicates the changes in pressure in kilopascals (kPa) as the participants inspire (increases in pressure) and expire (decreases in pressure). Therefore, swallows are represented in the respiratory data as flat areas.

The bottom graph represents the accelerometer readings acquired at the level of the hyolaryngeal complex as the complex raised and shifted forward thereby representing hyolaryngeal movement, i.e., the participant swallowed. Peaks in the accelerometer readings correlate with the anterior and superior movement of the laryngeal structure. The green line ('X Acc') indicates anterior/forward movement,



whereas the orange line indicates superior/raised movement. The orange line ('Y Acc') is the data of interest to this study. Note how many swallows are present and match the number with file name.

To match the apneic period with the corresponding point in the accelerometer data, the point of maximal hyolaryngeal elevation (peaks in the 'Y Acc' data) in the swallow was isolated as a landmark and used to determine the area of interest with regard to the respiratory data. The corresponding point on the respiratory graph is examined to determine the apneic period, i.e., no significant change in pressure.

2. ***Secondary Visual Inspection***

Additionally, this procedure permits the examiner to note which type of respiratory phase pattern occurred. Specifics on determining the respiratory phase pattern can be found in Step 4.

3. ***Determining the initiation time of swallow***

As the *Logger Pro 3* software allows for data to be divided into .02 second (s) intervals, the time at which the swallow was initiated may be established.

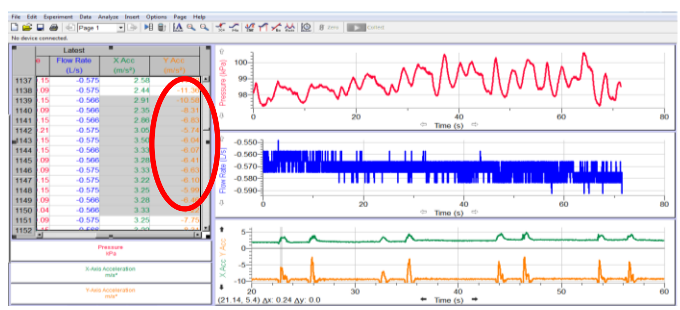
- Clicking the '*Examine'* button in the toolbar at the top of the data page (symbol: 'X=') will allow the examiner to scroll across both of the graphs in a vertical line which simultaneously present readings of the air pressure in kilopascals (kPa) and hyolaryngeal changes in movement (Y Acc-m/s²) at each contact point.
- To view an appropriate level of detail of the graphs, the examiner may left-click within the relevant graph and select the '*zoom-in*' function from the tool bar at the top of the page. It is important to have a fine view of the data so that peaks and troughs may be determined. To navigate the zoomed-in portion of the graphs, use the scrolling arrows at the horizontal and vertical axes. As this function

only magnifies one graph at a time, it is important to ensure that both are magnified. It would be useful to note the general times of each of the 'Y Acc' peaks.

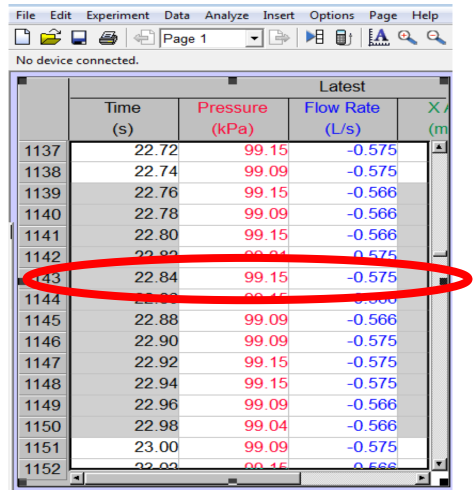
- As the examiner scrolls over the graphs, corresponding numerical data will be highlighted in the raw data table shown to the left side of the screen. Be aware that moving the mouse after highlighting a section of the graph will change the area of focus in the raw numerical table. Right-clicking the mouse before moving it over to the data table will avoid this issue.
- Left-clicking and dragging the mouse from any point on a graph will highlight a specific section in both of the graphs (respiratory and laryngeal movement) and the raw data table.

A swallow apneic period is defined as a section of the graph with a minimum of a .06 second (s) duration in which the respiratory pressure remains flat, i.e., no change in pressure. As indicated above, the general area of an apneic period on the respiratory graph can be deduced by the peak on the accelerometer graph associated with the swallow. The '*Examine*' feature permits the examiner to use the raw numerical data from the left-hand table to calculate the time at which a swallow was initiated.

- After isolating the general area of a swallow, i.e., the 'Y Acc' graph, zoom in to isolate the peak point of the swallow and highlight it.
- Moving over to the raw data table, scroll over to the 'Y Acc' (orange) data and find the numerical correspondence of the peak. This number may be a positive or negative value. You may wish to take note of the cell number of the peak to help you keep track of the location of the relevant data.



- Scroll left to identify the corresponding 'Pressure' (red) numerical values of the highlighted section. From the peak pressure, determine if there is an apneic period, i.e., no change in pressure over a minimum duration of .06 seconds (3 cells) *prior to or including the peak pressure of the swallow*. The peak point may not be the first point of an apneic period. If this happens, it was determined that the data preceding that particular peak point must be scrolled through to find an apneic period of .06 seconds preceding the peak.



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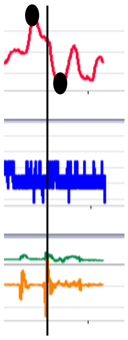
	Time (s)	Pressure (kPa)	Flow Rate (L/s)
1137	22.72	99.15	-0.575
1138	22.74	99.09	-0.575
1139	22.76	99.15	-0.566
1140	22.78	99.09	-0.566
1141	22.80	99.15	-0.566
1142	[illegible]	[illegible]	[illegible]
1143	22.84	99.15	-0.575
1144	[illegible]	[illegible]	[illegible]
1145	22.88	99.09	-0.566
1146	22.90	99.09	-0.575
1147	22.92	99.15	-0.575
1148	22.94	99.15	-0.575
1149	22.96	99.09	-0.566
1150	22.98	99.04	-0.566
1151	23.00	99.09	-0.575
1152	[illegible]	[illegible]	[illegible]

- Record the initial time (black) associated with the apneic period, i.e., the first cell in the continuous unchanging block of pressure in the '*Time*' column.

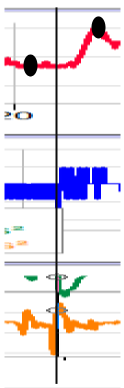
4. ***Calculating the location of the swallow***

To ascertain the relationship of a swallow within a respiratory limb, the initial and final points of a respiratory phase need to be identified and the times corresponding to these points recorded. This was accomplished by visually inspecting the respiratory graph ('*Pressure'*: red) and identifying the highest and lowest peaks preceding and following a swallow, as outlined below. For our study, the initiation and final points of a respiratory phase pattern were identified as follows:

Using the data regarding the initial time (in seconds) of swallow apneic periods and type of respiratory phase pattern, the point of a respiratory phase where a swallow occurred can be ascertained. The below graphs give general examples of respiratory phase shapes; however, make note of specific numerical changes in the respiratory pressure data to definitively determine where a respiratory phase begins and ends. In all the graphs below a solid, vertical black line denotes the location of the swallow apneic period and the round black markers the initial and final points of the swallow.



<u>Ex-ex</u>: The first point was identified as the point immediately following the *last* peak pressure in the inspiratory limb (in kPa) where the pressure begins to decrease. The final point was considered to be the *last* lowest point in pressure before the start of the rise of next inspiratory phase. *The last point is where there is no more ambiguity as to whether pressure is increasing or decreasing.*



<u>In-in</u>: The first point was identified as immediately following the lowest point of pressure of an expiratory limb and the final point was considered as the *last* peak pressure in the inspiratory limb immediately preceding the decrease in pressure of the subsequent trough.

<u>Calculating Percentage:</u>

The point at which a swallow occurred within a respiratory phase can then be determined and calculated as a percentage. This data was entered in an *Excel* file and a formula was entered to automatically calculate the percentage. The formula is explained below.

- <u>A:</u> Using the initial and final points for the respiratory phase patterns, identify the overall time (in seconds) of the respiratory phase by subtracting the final point of the phase from the initial point, i.e., Final time of respiratory phase – Initial time of respiratory phase = Time of overall respiratory phase (s).
- <u>B:</u> The time of the initiation of the apneic period (in seconds) is then subtracted from the initial point of the respiratory phase. This gives you the initiation of the apneic period within the respiratory phase, i.e., Time of swallow initiation – Initial time of respiratory phase = Time within respiratory phase when swallow was initiated (s).

- Taking the total time of the respiratory phase ('A'), divide by number derived in 'B'. Multiply this number by 100 to obtain a percentage. This is the point at which the swallow occurred represented as a percentage of the entire respiratory phase.
- Formula in *Excel* file: [(Swallow initiation – Initial time) / (Final time-Initial time)] X 100 = _____%