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Research Article

Association between the Electroglottographic Waveform and the Temporal Aspects of the Pharyngeal Swallow

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Abstract

The electroglottograph (EGG) has been used to measure the temporal aspects of laryngeal movement during swallowing.

Purpose

(1) To identify a correlation between the duration of onset and offset of the EGG signal to the overall timing of the pharyngeal swallow with different bolus volumes and viscosities. (2) To consider the application of the EGG as a pharyngeal temporal measurement tool for use in behavioral dysphagia therapy.

Method

Participants include 30 healthy females, aged 18 – 25 years. Each participant performed ten swallows (i.e. 5 water swallows & 5 applesauce swallows) during which time EGG activity was measured.

Results

The mean duration of the swallow for the puree consistency was 1.14s (M = 1.13503, SD = .584536) and 0.88s for the thin liquid consistency (M = .88371, SD = .346475) when measured using waveform analysis software. Pharyngeal swallows were also typically faster for water versus applesauce swallows. Significant intra- and inter-rater reliability of EGG data for trials of water (ICC coefficient = .9904 and .9854) and applesauce (ICC coefficient = .9776 and .8654) was observed, respectively.

Conclusions

There is preliminary support for the possible clinical application of electroglottography as a pharyngeal temporal measurement tool in traditional dysphagia therapy.

Keywords: Adults; Dysphagia; Swallowing; Service delivery; Intervention

Introduction

The electroglottograph (EGG) was developed as a noninvasive tool for measuring the electrical impedance variations (i.e. the amount to which the tissue resists the flow of electrical current) that are associated with vocal fold vibration and thus fundamental frequency during phonation [1-9]. Electroglottography involves the horizontal placement of a pair of plate surface electrodes, held in firm place with a Velcro strap or neckband on each side of the larynx at the level of the thyroid lamina. A high frequency signal (between 300 kHz and a few megahertz) with a low current (0.05V) flows in both directions through the neck between the electrodes [1,2,6]. Typically, recognized speech frequencies occur between 300 and 3,000Hz. The current that has passed through the skin and laryngeal area is amplitude modulated (i.e. the signal strength of the carrier wave is varied in proportion to the waveform being transmitted) by the vibrating vocal folds and the resultant Lx signal (i.e. waveform) is displayed as a demodulated waveform (i.e. the original information-bearing signal) on the computer screen [1,2,4,6]. Thus, the strength of the amplitude signal reveals trans-neck impedance over time [1,2,6].Impedance is affected by the size, shape, orientation, and chemistry of the tissues and fluids in the pathway of the current [6].

During phonation, electrical impedance will increase with vocal fold abduction and decrease with vocal fold adduction. The EGG signal being depicted; however, is of the contacting and decontacting phases of the vibratory cycle, not the open and closed phases. The output signal does not represent the glottal area (i.e. the space between the true vocal folds) but instead provides the overall status of the larynx as a unit [2,6]. The orientation of the EGG waveform is shown with increasing vocal fold adduction / contact area (not maximum glottal closure) and decreasing resistance, upward and increasing vocal fold abduction / minimal contact area and peak glottal flow, downward [1,2,4-6].

Historically, the clinical application of EGG has been primarily for biofeedback purposes during voice therapy; however, investigators have also used the electroglottograph in measuring the temporal aspects of laryngeal movement during swallowing [7-10]. Low-frequency impedance changes for tracing the vertical movement of the larynx were found [7,8], and use of the EGG as a possible biofeedback tool during the provision of behavioral dysphagia therapy has been suggested [7-9].

Although the video fluoroscopic swallowing evaluation (VFSE) and the flexible endoscopic evaluation of swallowing (FEES) are the preferable methods used in the assessment of oropharyngeal swallow function, neither is an amenable technique for a clinician as a temporal measurement tool during dysphagia therapy. Video Fluoroscopy is a radiographic procedure that permits evaluation of the swallowing process as the patient is administered graduated bolus volumes of different radiopaque consistencies [11]. Findings are used to guide the clinician in selecting treatment techniques but the VFSE is not used directly in the delivery of behavioral dysphagia treatment. FEES, on the other hand, is used in restorative rehabilitation by the speech-language pathologist for patients diagnosed with dysphagia. Exercises used to treat the problem of an ineffective swallow, a misdirected swallow, and/or a delayed or mistimed swallow can be taught during a FEES examination following a biofeedback paradigm [12]; however, the FEES technique is invasive, does require extensive training on the part of the endoscopist, and also requires interdisciplinary team support for use from the clinician's facility.

In today's healthcare environment, with the pressures of using evidenced-based practice (EBP) and satisfying the regulations for the provision of therapy under the auspice of Medicare, Medicaid, and manage-care companies, clinicians need a non-invasive, cost-effective, and innocuous tool for clinical therapeutics. However, understanding the association between the duration of onset and offset of the EGG signal to the overall timing of the pharyngeal swallow with different bolus volumes and viscosities is warranted for the clinical application of EGG as a rehabilitative measurement tool.

The purpose of this study was to identify and compare the capture duration of the swallow (i.e. the duration between waveform signal onset and offset) of different viscosities in neurotypical young adults as represented by the EGG waveform. In addition, this study attempted to validate the application of the EGG as a possible measurement tool for use in behavioral dysphagia therapy, specifically measuring pharyngeal swallow duration and to use electroglottography to obtain objective data in support of determining the timing / scheduling of the instrumental re-evaluations.

Methods

Participants

The study included 30 healthy female college students, aged 18 – 25 years. All participants reported, by way of a questionnaire, to be in good health with no history of dysphagia, any neurologic disorders, respiratory diseases, head and neck surgeries and/or injuries, GERD, or smoking. None of the participants were taking any medications known to affect swallow function. All participants presented with typical oral anatomical structures and complete dentition. Participant selection was based on the results of a study by Kleinjan and Logemann, Rademaker et al. and Schultz et al. [9,13,14]

Equipment

Prior to each data collection session with each participant seated in an upright position, the EGG unit and contact electrodes were cleaned according to the manufacture's guidelines. EGG activity was measured using the KayPENTAX Electroglottograph Model 6103 that was interfaced with the Visi-Pitch, Model 3950B using the Real-Time EGG and Waveform Editor Analysis software. A sampling rate of 11025 Hz was used. A pair of EGG manufacturer transducers, each with a 1.25" diameter, was held in firm contact on the neck on either side of each participant's thyroid cartilage at the approximate level of the vocal folds, using the supplied neckband. The thyroid cartilage was initially centered horizontally in reference to the single electrode array. Optimal placement was determined by moving the electrodes until a maximum output Lx signal was obtained, reflecting maximum amplitude during swallowing [8] when the participant was asked to swallow a 10-mL bolus of room temperature water.

Experimental Task

Once proper placement of the single electrode array was achieved, each participant was instructed to perform a total of ten swallows: 5 separate swallows with 10-mL of room temperature water [8] and 5 separate swallows with 10-mL of room temperature applesauce, by way of a calibrated syringe. EGG output can be affected by movements of the head and neck; therefore, the participants were instructed to limit upper body actions during the data collection period [9]. Once the bolus trial was administered, the participant was instructed to swallow the bolus in one swallow "as typically as possible".

EGG Waveform Capture Duration

Following visual inspection of the EGG waveform signal from the display in the EGG contour window, the onset and offset of the swallow was identified using the vertical cursors. The data, outside the cursors were trimmed and the selected data saved. This segmentation of the EGG cycle was then viewed using the Waveform Editor software. Duration measures of the swallow were obtained between the onset and offset markings in seconds.

Reliability of Measurements

The EGG signal required visual inspection and segmentation in order to obtain waveform measurements. The reliability of this procedure therefore, needed to be established. Swallowing samples of each task (i.e. water and applesauce swallows) of 6 randomly selected participants (i.e. 20% of the 30 participants) was analyzed to judge intra- and inter-judge reliability. Data was measured using correlational analyses.

Results

Our primary finding was that the duration of the pharyngeal swallow was typically faster for 10ml swallows of water than for 10ml swallows of applesauce when measured using electroglottographic and waveform analyses. Secondly, mean pharyngeal swallow durations of 1.14 and 0.88s were measured from the EGG waveforms and using waveform editor analysis software for swallows of puree and thin liquid consistencies, respectively. Durational measurements of each swallow for both thin liquid (i.e. water) (5) and puree (i.e. applesauce) (5) consistency trials were made using the KayPENTAX Electroglottograph Model 6103 which was interfaced with the Visi-Pitch, Model 3950B and using the Real-Time EGG and Waveform Editor Analysis software.

The mean duration of the swallow for the puree consistency (M = 1.13503, SD = .584536) was greater than the mean duration of the swallow for the thin liquid consistency (M = .88371, SD = .346475). A paired *t-test* performed on 30 participants between the mean durational values of thin liquid and puree swallows revealed a statistically significant difference beyond the .05 level: $t(29) = -2.608$, $p = 0.014$ (two-tailed). The 95% confidence interval on the difference was [-.448426, -.054221], which did not include the value zero specified by the null hypothesis. This finding indicates that mean pharyngeal swallow duration is faster for 10mL water boluses than for 10mL applesauce boluses in typical females aged 18 to 25 years when measured using EGG and waveform analyses.

A one-way within-subject analysis of variance (ANOVA) was performed on swallow duration as a function of swallow trial of thin liquids. The participants were measured on swallow duration over five consecutive trials of thin liquid (1st, 2nd, 3rd, 4th, and 5th trials). For each ANOVA, the assumption of sphericity was not met, so Huynh-Feldt-corrected degrees of freedom were used for the average tests of significance. Levels of significance were computed using an alpha level of 0.05 on all analyses. There was not a significant difference on swallow duration depending on swallow trial of thin liquids, $F(3.606, 104.586) = 0.898$, $p = .460$.

A one-way within-subject analysis of variance (ANOVA) was performed on swallow duration as a function of swallow trials of puree consistency. The participants were measured on swallow duration over five consecutive trials of puree consistency (1st, 2nd, 3rd, 4th, and 5th trials). For each ANOVA, the assumption of sphericity was not met, so Huynh-Feldt-corrected degrees of freedom were used for the average tests of significance. Levels of significance were computed using an alpha level of 0.05 on all analyses. There was not a significant difference on swallow duration depending on swallow trial of puree consistency, $F(2.573, 74.624) = .702$, $p = .533$.

Due to the possible influence of subjective human error and variability in analysis of EGG data, 20% of EGG data in each condition were randomly reanalyzed using the intra-class correlation (ICC) coefficient. Significant intra-rater reliability of EGG data for trials of water (ICC coefficient = .9904) and applesauce (ICC coefficient = .9776) was observed within rater. Additionally, significant inter-rater reliability of EGG data for trials of water (ICC coefficient = .9854) and applesauce (ICC coefficient = .8654) was observed between raters.

Discussion

The process of designing a management plan for a person who is diagnosed with dysphagia includes use of the information commonly obtained from the VFSS or FEES examination. Once a behavioral dysphagia plan is implemented common patient and family questions arise: "When can I have water?" and "When can I be upgraded?" The speech-language pathologist uses subjective-clinical judgement to determine the timing/scheduling of a "follow-up" objective assessment, if indicated. Typically, if a patient is receiving modification of food and or liquid consistencies due to physiological dysfunction, the speech-language pathologist may recommend a re-evaluation of function via VFSS or FEES to determine if the suspected improvement that has been demonstrated in therapy is adequate to justify an "upgrade" of bolus type and viscosity.

The current investigation was designed to determine if using EGG to obtain temporal measurements of the pharyngeal swallow is an option for clinician's practicing in a therapeutic environment, to objectively determine the timing/scheduling of the instrumental re-evaluation (i.e. VFSS or FEES). The preliminary data obtained supports the notion that there may be a way to sample components of the swallow in a reasonably noninvasive way in order to obtain durational measures relative to pharyngeal and laryngeal events. Traditionally, EGG is considered an unobtrusive tool that is used to obtain electrical impedance measures during phonation. The resultant waveform reveals impedance shifts that correlate to vocal fold contact area [15].The electrical signal changes with vocal fold adduction and abduction as the vocal fold contact area increases and decreases, respectively.

During the pharyngeal phase of the swallow, the bolus moves inferiorly through the pharynx. Sequential anatomical movements include: lingual retraction, posterior pharyngeal wall constriction, medial and anterior movement of the arytenoid cartilages, epiglottic retroflexion with simultaneous hyolaryngeal elevation, adduction of the true and false vocal folds which stimulate the apneic reflex, and relaxation of the upper esophageal sphincter (UES), often termed the pharyngoesophageal segment (PES). It was hypothesized; however, that if the electrical impedance that occurs during the apneic period (i.e. vocal fold contact) could be measured electroglottographically and visualized using waveform analysis, then the time between the onset and the offset of the signal (i.e. pharyngeal swallow duration) could be calculated in seconds.

Female participants (30) aged 18 to 25 years produced five swallows each of 10-mL applesauce and 10-mL water boluses. The mean pharyngeal swallow duration of 1.14 and 0.88s measured from the EGG waveforms and using waveform editor analysis software was obtained for swallows of puree and thin liquid consistencies, respectively. These temporal measurements are in agreement with Klahn and Perlman [16] who reported a mean of 0.73s (SD 0.14) for 5-mL applesauce volumes and 0.76s (SD 0.19) for 5-mL water volumes from 6 typical adult female participants aged 18 to 25 years using a first-generation Respirodeglutometer. Sonies et al. [17] reported a mean of 1.30s +/- 0.30 for 10-mL water boluses using ultrasound examination from 8 typical adult female participants aged 18 to 34 years, and Hiss et al. [18] identified a mean swallowing apnea duration of 0.77s (SEM 0.18) for 10-mL water boluses from 10 typical adult female participants aged 20 to 39 years.

In addition, our data indicate that the temporal measures obtained for 10-mL water and 10-mL applesauce boluses are plainly different, with the duration of the pharyngeal swallow for thin liquid consistencies (i.e. water) being quicker than that of the puree (i.e. applesauce) boluses (p = 0.014). Klahn and Perlman [16] also reported differences in duration (seconds) of deglutition apnea for various viscosities as well as gender of participants. These disparities were thought to be associated with the displacement differences that occur between males and females during swallowing. Furthermore, waveform patterns did not show a significant difference for pharyngeal swallow duration between participants and across repeated swallows (p = .460 and p = .533 for thin liquid and applesauce, respectively). This finding lends support for the application of this technique as a possible clinical tool that would require further investigation. Baylow et al. [19] also reported preliminary evidence of latent temporal events of pharyngeal transit time and pharyngeal delay time, within 1-mL trial swallows of liquid barium, in adults with acute stroke when an effort was made to "fatigue" the swallowing mechanism. Typically, patients who have been diagnosed with post-stroke pharyngeal dysphagia receive a course of traditional behavioral rehabilitation. Clinicians frequently then use their "best judgment", based on the patient's "progress", to make changes to the patient's plan of care. Electroglottography may be used by the clinician as a non-imaging instrumental technique, to measure changes in the timing of the pharyngeal swallow and thus determine the need for further rehabilitative imaging assessment. Although, this tool does not provide information specific to the advancement of the bolus through the pharynx in relation to structural movement from the onset to the termination of the swallow, it does provide cursory pharyngeal timing information.

It appears that there may be a simultaneous relationship between the duration measure that is obtained from the point of swallow onset to offset when the EGG waveform signal is analyzed to temporal measures of pharyngeal swallow duration that have been previously reported using other types of instrumentation (e.g. videofluoroscopy, ultrasound) [13,16-18]. Although the onset and the offset of the swallow could not be verified using the Real-time EGG amplitude scale due to software amplitude limitations, nor was a meaningful EGG closed quotient obtained because of the lack of vocal fold contact modulation, visual inspection of the waveform clearly showed a fairly consistent change in the EGG pattern during swallowing (Figure 1). At times, there were observable differences between participants, specifically in the oral preparatory stages of the swallow; however, there was uniformity between the participants during the swallow when the hyo-laryngeal complex ascended through the approximate time of descent. In turn, there was consistency in the resultant waveform patterns.

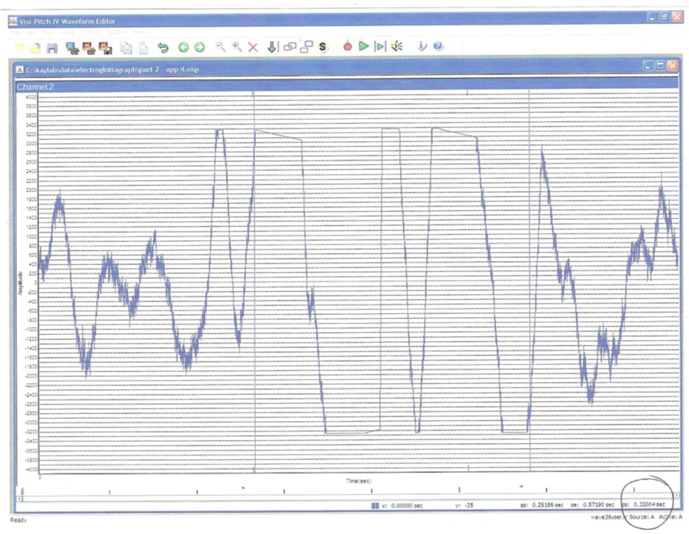

Figure 1. Waveform analysis of the onset and offset of the swallow.

Conclusion

The purpose of this investigation was to offer the use of EGG as a clinical tool for obtaining pharyngeal swallow duration measures during dysphagia therapy. This information could be potentially useful in assisting the clinician in determining the timing/scheduling of VFSS and/or FEES re-evaluation. EGG with waveform analysis may also be considered a cost-effective pharyngeal temporal measurement tool for use in behavioral dysphagia therapy in which the patient is attempting to improve swallowing parameters. A limitation of the study is the lack of simultaneous VFSS or FEES during data collection. Concurrent instrumentation would be warranted with future investigations as well as data collection with an aged matched group of neurologically impaired (e.g. acute CVA) participants.

Our data provides preliminary support for the possible clinical application of electroglottography as a pharyngeal temporal measurement modality that could enhance traditional intervention methods used in treating individuals diagnosed with swallowing disorders. Clinicians would be able to collect objective pharyngeal timing measures during therapy using non-imaging techniques, in order to provide substantive restorative support for swallow re-evaluations following the initial videofluoroscopy or flexible endoscopic evaluation of swallowing procedure.

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