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Abstract

Speech-language pathologists frequently use surface electromyography (sEMG) biofeedback techniques as a tool to facilitate therapy in patients with swallowing disorders. Data are needed to compare disordered swallow strength to normal swallow strength. The present study establishes a normative database on normal swallowing force in two age groups, 18-25 year olds and 60 years and older. In addition to this database, this investigation also sought to answer three questions: 1) Do older adults (60+) swallow with less force than young adults (18-25)? 2) Is there a difference in the amount of swallowing force elicited between the voluntary process and the swallow to command process? 3) Are there differences in swallowing force between the sizes of bolus that are being swallowed? Swallow to command swallows were compared to voluntary swallows on 5ml, 10ml, and 20ml of water. Statistical analysis comparing participant age and swallowing process showed that there is a significant increase in swallowing force during the swallow to command and no difference in swallowing force between participant age groups. There were no significant differences in either voluntary or swallow to command tasks. We conclude that in swallowing therapy using sEMG it may be more beneficial to use swallow to command procedures where muscle recruitment is higher so that swallowing function can be facilitated.

Introduction

Speech-language pathologists frequently use surface electromyography biofeedback techniques (sEMG) in therapy with patients with swallowing disorders. Biofeedback techniques may help patients learn complicated swallowing maneuvers by providing a visual or auditory reinforcer when the desired movement has been accomplished. [1] These sEMG techniques provide a non-invasive, fast, and portable tool to utilize in therapy and evaluation of swallowing disorders. [1] sEMG biofeedback utilizes electrodes coated in conduction gel that are placed on the surface of the skin. [1] The electrodes measure the electrical activity of the muscle groups underneath them. Although electrical activity from specific muscles is difficult to determine, sEMG biofeedback is sensitive in recording the amplitude and duration of electrical activity in general muscle groups.[1] Using sEMG in conjunction with videofluoroscopic technology, Crary and Groher (2000) identified sites of electrode placement that corresponded to muscle group activation in the swallow.[1] They found that suprahyoid site electrode placement corresponds to laryngeal elevation and constriction in the pharynx showing that sEMG is sensitive to swallowing activity of specific muscle groups.[1]

Validity of the sEMG unit and electrodes has been shown in regards to measuring specific muscle groups associated with swallowing, however reliability and validity of the investigator conducting the sEMG procedures is also important.

Crary, Carnaby, and Groher (2007) investigated the validity and interjudge reliability of clinicians to interpret the sEMG signal in reference to swallowing.[2] sEMG graphic traces were simultaneously presented with videofluoroscopic images of forty four healthy adults to five experienced clinicians and eight inexperienced clinicians.[2] Identification of swallows using the sEMG graphic records indicated high validity estimates and a strong degree of accuracy in identifying swallows.[2] Experienced judges had a higher degree of agreement then inexperienced judges, however interjudge reliability estimates indicated strong agreement among judges in both groups in the identification of swallows.[2] This investigation shows that the sEMG signal is a reliable and valid instrument for identifying swallowing activity.[2]

Surface electromyography has been used extensively in the swallowing treatment of patients following brainstem stroke. Particularly, to help patients learn Mendelsohn's Maneuver, a maneuver that prolongs swallow activity resulting in wider opening of the upper esophageal segment. Huckabee and Cannito (1999) retrospectively reviewed the treatment of ten patients with dysphagia at least eight months post onset of brainstem stroke using sEMG and measurements of physiologic progress using videofluoroscopy.[3] This review reported the functional outcomes with diet of patients who underwent an Accelerated Swallowing Treatment Program.[3] The program involved ten hours of intensive, clinician directed therapy in one week that was paired with three home therapy sessions.[3] Although this program used videofluoroscopy to evaluate swallowing ability and progress in treatment, clinician directed therapy and home rehabilitation was facilitated with the use of sEMG biofeedback. sEMG biofeedback was used to foster the rapid learning of compensatory swallowing maneuvers such as the modified valsalva, the Mendelson maneuver, the Masako maneuver and the head-lift maneuver.[3] Biofeedback was used as a measurement tool of the interim progress of patients during and between sessions of these maneuvers as well as swallowing timing and force so that videofluoroscopy did not have to be repeated frequently as an outcome measure.[3] Since videofluoroscopy is a more invasive and costly procedure, sEMG biofeedback saves both time and patient comfort in assessing progress of swallowing. At six month follow-up, six of the ten patients had returned to a full oral intake, and severity scores on videofluoroscopy had decreased significantly from pretreatment to posttreatment.[3] Huckabee and Cannito (1999) concluded that sEMG biofeedback is an effective and easy tool for treating swallowing disorders and that sEMG could be used as a measurement tool to document progress.[3]

Crary, Carnaby, and Groher (2004) also conducted a retrospective review on sEMG treatment of twenty-five patients with dysphagia post stoke and twenty patients with dysphagia post head/neck cancer.[4] The systematic therapy program was evaluated by functional outcome, time spent in therapy, and cost per unit of therapy. [4] Patients underwent about six therapy sessions per week for a maximum of twenty eight therapy sessions. After patients completed the sEMG therapy regiment their oral intake was reassessed to establish a change in overall swallowing function. [4] After treatment, ninety two percent of patients in the post-stroke group showed an increase in functional oral intake after treatment as well as eighty percent of the post head and neck cancer patients. [4] Results of this study show that sEMG can facilitate swallowing function and improve oral intake in patients in a time-limited approach with minimal costs. [4]

Swallowing treatment using sEMG can be cost effective and simple not only due to the speed of therapy but because most sEMG units are portable and can offer the clinician many treatment options. Typically, the clinician selects a target goal of swallow force and the patient attempts to reach that target, or to sustain their swallow force as in the Mendelsohn maneuver.[1] Normally, swallowing practice involves the use of small amounts of semi-solids and liquids. Prior to swallow attempts during the treatment session the clinician measures the resting baseline of muscle activity and compares this to the patient's performance on the swallowing task. Normal resting baselines usually range between one and four microvolts.[1]

Vaiman (2007) noted that while sEMG has been used primarily as a treatment tool for dysphagia, it may also be used as a non-invasive diagnostic tool.[5] Further, he noted that without normative data on swallowing force, clinicians might not know how to set realistic swallow force thresholds during treatment sessions.[6-8] Therefore, Vaiman, Eviatar, and Segal (2004) collected normative data on the timing and amplitudes measures of four hundred and forty adults with normal swallowing abilities. [6-8] These data included the mean, standard deviation, minimum and maximum force during swallows, the range of performance, and the duration for each swallow using electrode placement sites on the orbicularis oris, masseter, submental, and infrahyoid muscle groups. [6-8] A baseline was collected for each participant at the start of testing for each site and was not retested during procedures. [6-8] Participants completed four swallowing tasks that included a voluntary saliva swallow, voluntary single water swallows, voluntary single swallows of 20cc of water, and voluntary drinking of 100cc of water. [6-8] All swallowing tasks were voluntary, without investigator command to swallow. Five age groups, each consisting of seventy participants were tested using these procedures, 18-30,31-40,41-50,51-60, 61-70, and 70 +. [6-8] The only differences in swallowing force between groups were found between the 18-30 year old group and the 70+ age group; however, swallowing function in general was shown to be extremely variable in all age groups. [6-8] These data provide a normative database of parameters of muscle activity required for swallowing to be used as a measurement tool to detect abnormal swallows in patients complaining of oropharyngeal dysphagia, and potentially provide normative values of expectation of swallowing force and amplitude during swallowing treatment. [6-8] Vaiman, Eviatar, and Segal (2004) concluded that sEMG biofeedback could be used to differentiate and evaluate the muscle activity involved in the three stages of swallowing. [6-8]

Although these investigations provide valuable information and a large database across a wide age spectrum, there are some limitations that can be rectified. One of the first and major problems is that Vaiman, Eviatar, and Segal (2004) only took one resting baseline to measure static muscle activity at the start of testing procedures. [6-8] With only one baseline it is misleading and difficult to see where a patient's true range of swallowing ability falls. When using these normative data to compare to a patient with a swallowing disorder, it would be almost impossible to see if a patient fell within normal limits without knowing the baseline value prior to swallow onset in order to compare it to their maximum effort. Taking one baseline at the start of swallowing tasks is not sufficient to establish this starting point since static muscle activity will change throughout the procedure. Ideally a baseline should be documented before each swallowing attempt in order to document the maximum force expended. After the patient swallows, their maximum amplitude is recorded. The baseline score would then be used to calculate the difference between the maximum amplitude value and the initial baseline giving the true range. This would give the clinician an accurate measurement of the patient's performance on that swallow trial.

The second limitation in this study is that Vaiman, Eviatar and Segal (2004) only tested the volitional swallowing process. [6-8] Even though a major component of swallowing function is volitional; many therapy trials in a swallowing treatment session also use exercises involving swallows to command. Leaving these exercises out of testing could make it difficult for a practitioner who is using commanded trials to use a database that did not incorporate these procedures. Palmer et al. (2007) found that the number of chewing cycles, the duration of food processing, and the position of the bolus in the foodway changed when normal patients were asked to swallow to command versus swallow when ready (voluntary). [9] These differences were observed during videofluoroscopy when eight patients with normal swallowing were asked to chew a hard cookie, signal when they were ready to swallow, and then wait to be given the command to swallow by the investigator (swallow to command), and chew and swallow the hard cookie like they normally would (voluntary swallow).[9] Palmer et al. (2007) found that during the swallow to command process the number of chewing cycles were greater, the duration the food was processed was longer, and that the position of the bolus in the foodway was higher at the onset of swallow to command compared to voluntary swallows.[9] These findings suggest that patients can consciously control the stages of swallowing with different neural mechanisms that may dictate voluntary and commanded swallows.[9] This also provides evidence that the differences between voluntary and commanded swallows may also affect swallow duration and amplitude due to bolus positioning and control of the foodway.[9] With this evidence, completing only voluntary swallowing tasks provides data on only one type of neural mechanism and makes Vaiman, Eviatar, and Segal's database misleading and difficult to use comparatively in therapy of swallowing disorders by clinicians.

A final limitation in Vaiman, Eviatar and Segal (2004) is that the bolus sizes are difficult to standardize. In the investigation, some swallowing trials involved swallowing average amounts of tap water according to age group.[6-8] This procedure allows different age groups to swallow different bolus sizes and takes away from standardization across participants. Participants are also required to swallow their own saliva and in some trials continuously drink 100cc of water.[6-8] Both of these tasks have unregulated bolus volumes and detract from overall standardization. In order to make results of research comparable and replicable, procedures should be standard across participants and easily duplicated. In a survey of three hundred clinicians, McCollough et al. (1999) found that the most common bolus volume preferred for standard diagnostic swallowing procedures was 5ml and 10ml.[10] Adnerhill, Ekberg, and Groher (1989) also conducted a study in order to find the most suitable bolus size for three age groups during pharyngoesophageal evaluation.[11] They found that the normal bolus size for all age groups was 20ml.[11] These investigations show the beginnings of standardization in swallowing evaluation as well as justification for using specific bolus sizes for different age groups in swallowing diagnostics.

The present study was designed to establish a database on normal swallow force in two age groups accounting for changes in initial baselines prior to swallow. Although previous studies have tested participants across a wide age range, due to inconclusive results in middle ages we have collapsed the age groups to include only the most distinct ages, 18-25 year olds and 60 years and older. Together with baseline data, this investigation also incorporates the testing of two separate yet widely practiced processes of swallowing: swallowing to command and swallow when ready (voluntary) while swallowing standard volume sizes. These swallowing tasks will be elicited while swallowing the standardized bolus volumes of 5ml, 10ml, and 20ml.[10,11] In addition to establishing a normative database on swallowing force, this investigation sought to answer three questions: 1) Do older adults (60 years and older) swallow with less force than young adults (18-25 years old)? 2) Is there a difference in the amount of swallowing force elicited between the voluntary process and the swallow to command process? 3) Are there differences in swallowing force between the sizes of boluses that are being swallowed?

Methods

Participants

Volunteers were recruited during a six-month period from the University of Redlands (Group 1) and local adult day facilities (Group 2). Volunteers were grouped based on two age groups: Group 1, between 18 and 25 years of age (n=30) and Group 2, 60 years and older (n=30). Prior to the study, volunteers completed a brief medical questionnaire regarding their current health and previous medical history. Volunteers had no history of dysphagia, no previous head or neck surgery or cancer, respiratory disease, muscle disease, neurological disorders, and were not currently taking medications that could affect their swallowing. The methods of recruitment and all procedures in the present study were approved by the Institutional Review Board at the University of Redlands.

Materials and Procedures

After cleaning the neck with an alcohol swab, one pre-gelled adhesive 1 ½ in. strip electrode with one ground and two referent electrodes was placed on the suprahyoid site of the volunteer's neck to the right of the midline. This placement provides measurements in correspondence to laryngeal elevation and constriction of the pharynx.[1] The sEMG recordings were made using the Pathway MR25 (The Prometheus Group, Dover, NH). Muscle activity was monitored using the 'max' (maximum) setting. This setting allows the investigator to read baseline muscle activity while the down arrow at maximum setting is held. When the down arrow key is released the sEMG unit measures and records the maximum force of the swallow in microvolts. To conduct the swallowing tasks, 30ml medicine cups were used. Volunteers drank two sets of 5ml, 10ml, and 20ml of water from these cups during two swallowing tasks. [10, 11]

After the electrode placement, volunteers were asked to perform two swallowing tasks. The first swallowing task consisted of holding a small amount of water that was consumed from the small medicine cup in their mouths until a static baseline was established. A baseline was established and recorded when the muscle activity remained constant for over one second. Participants held the water in their mouths for 3 to 5 seconds. Participants were instructed not to play with the water held in their mouths and to swallow all of the water in one swallow when the investigator gave them the command "swallow." After the command "swallow" was given, the maximum force of the swallow was recorded in microvolts. This process was repeated with 5ml, 10ml, and 20ml of water with 5 to 10 seconds between tasks.

The second swallowing task involved volunteers drinking the water from the cup and swallowing the water in a single swallow when ready (voluntary swallow). Volunteers were instructed to make sure all of the water from the cup was in their mouth before swallowing and to tap on the table when they began to swallow the water. A baseline was recorded in microvolts while the water was sitting in the volunteer's mouth immediately before the tap. This baseline was recorded by observing static muscle activity before the moment of swallow. The maximum force of the swallow was recorded after the volunteer tapped the table to signify they had begun to swallow the water. This task was also repeated with 5ml, 10ml, and 20ml of water with 5 to 10 seconds between tasks.

Volunteers in both groups were given both tasks in a random order including the order of the volume of water to be swallowed. A total of six swallows and six baselines were obtained for every participant.

Data analysis:

Data were recorded according to swallowing task type, swallow to command or voluntary swallow, with a baseline and a maximum measurement of the swallow in microvolts for 5ml, 10ml, and 20ml of water. Based on a total of six swallowing tasks, twelve measurements were taken for each participant. These measurements were recorded on individual spreadsheets for each participant that included only their participant number and the order of the swallowing tasks followed by the measurements.

These data were organized into a larger spreadsheet that recorded the age group of the volunteer, gender, participant number, and their twelve recorded swallows. The average of the three voluntary swallowing baselines, the average of the three voluntary swallowing maximum forces, the average of the three swallow to command baselines, and the average of the three maximum swallow to command maximums were also calculated between all volumes of water (5ml, 10ml, 20ml) for each participant. The average maximum minus the average baseline was calculated to determine the overall change in force for each task. These Average Ranges were used in a statistical analysis that compared participant age group with swallowing process, voluntary and command. Ranges were also calculated between the maximum swallowing force and baseline score for every volume and process. These True Ranges were used in statistical analysis that compared the different volume amounts to swallowing force.

The data were analyzed using the computer program SPSS. A 2x2 Mixed Analysis of Variance (ANOVA) was conducted to examine the effect of participant age and swallowing process on swallowing force. A repeated-measures ANOVA was also conducted on the True Range calculations to compare the swallowing force during each water volume (5ml, 10ml, 20ml) in both the swallow to command and voluntary processes.

Results

A normative database was created based on the mean of swallowing force, standard deviation, minimum, maximum, average baseline and average maximum force measurements for each volume (5ml, 10ml, and 20ml) and for each process, voluntary and command, for Group 1 (18 to 25 year olds) and Group 2 (60 years of age and older) (Table 1). The average baseline was calculated by taking the recorded baseline from each participant in the group for the volume swallowed and obtaining the average. The average maximum was calculated by taking the maximum force recorded from each participant in the group for that volume swallowed and calculating the average. The minimum column accounts for the minimum baseline force that was recorded for that volume of water swallowed and the maximum is the maximum force that was recorded for that volume of water swallowed. The mean force and standard deviation were calculated based on the average baseline and average maximum force for that volume of water swallowed.

A 2x2 Mixed ANOVA was used to examine the effect of participant age and swallowing process on swallowing force. There was no main effect of age, F (1, 58)=2.321, p=0.133. Group 1 (M=7.59) and Group 2 (M= 6.21) did not differ in swallowing force. However, there was a main effect of swallowing process, F (1, 58)= 11.942, p=0.001. Participants swallow with greater force in the swallow to command condition (M=7.61) than the voluntary condition (M=6.18). There was no interaction between participant age and process, F (1,58)=0.462, p=0.499.

Due to the lack of interaction between age and process in the first analysis, the data from Groups 1 and 2 were collapsed into one group for analysis of volume (5ml, 10ml, and 20ml). A repeated-measures ANOVA was conducted to compare the swallowing force during each volume of water. Comparison of swallowing force during the three volumes swallowed in the voluntary process revealed no significant differences in swallowing force between 5ml (M= 6.01), 10ml (M= 6.48) or 20 ml (M=6.20), F (1, 60)= 0.499, p=0.608. Analysis of swallowing force during the swallow to command process between 5ml (M= 7.15), 10ml (M= 7.62), and 20ml (M= 7.90) also revealed no significant differences, F (1, 60)= 2.551, p=0.082.

Statistical analysis shows that swallow to command ranges are significantly larger than voluntary ranges, however, the normative database average baselines for the voluntary process appear to be higher than those for the swallow to command process. The average baselines in both Groups 1 and 2 of the voluntary process appear to be out of the normal range for baseline scores, 1-4 microvolts.

Discussion

The normative database in this investigation utilizes true ranges that include baseline measurements recorded before every swallowing attempt. These baselines are important in the comparison of patients with swallowing disorders to normal participants in this database because it gives clinicians a true starting point from which to make their judgments. Although the baselines for each swallowing task are averaged, minimum swallowing force is provided so that clinicians are able to see the lowest recorded baseline (Table 1). This information is necessary to see where a swallowing range started from so the true range can be correctly determined. Previous research gathering normative data on the force of swallow is very difficult to use for comparison due to lack of baseline data and difficulty interpreting maximum force data.

Although age was not a significant factor affecting swallowing force, there was a significant difference between the force of swallowing in the voluntary process and the swallow to command process for both age groups. A significant increase in swallowing force was found in the swallow to command process in both groups. This finding is important for the evaluative and therapeutic uses of sEMG biofeedback because it not only shows a definite difference between the two processes, but a higher level of muscle recruitment in the swallow to command process. When the patient is required to exert maximum force using the swallow to command task, then it is likely that this procedure will facilitate swallowing function. This approach to treatment is similar to the idea utilized in the Accelerated Swallowing Treatment Program in Huckabee and Cannito (2007) that if the muscles of swallowing are working more efficiently then progress in therapy will occur in a shorter amount of time.[3] Since this muscle output is seen in the form of higher swallowing force on sEMG biofeedback it would be more beneficial in treatment to use the swallow to command process.

As an assessment tool, this higher muscle engagement and maximum force can be useful in assessing potentials for target thresholds of performance. If assessing under the voluntary condition, this investigation shows that muscles will not be exerting maximum force and may not be completely engaged. If assessments need to measure the maximum force at which a patient can swallow, then they need to assess that patient in the swallow to command mode. This difference in muscle engagement and exertion regardless of age might be due to the neurological elicitation of the command swallow as opposed to the more reflexive nature of the voluntary swallow.[9] When a swallow is elicited through the swallow to command procedure, more thought and concentration may result in increased effort and recruitment of muscle groups resulting in increased swallow force.[9] Although this new information needs further testing, it provides valuable information for the procedures and assessment techniques that clinicians routinely use on patients with swallowing disorders who may be candidates for sEMG-assisted treatment.

Even though the swallow to command process elicited higher maximum forces, the normative database showed higher baseline muscle activity in the voluntary process. All of the measurements for both age groups and for all volumes in the voluntary process were recorded at higher levels than the normal range of baseline activity of 1-4 microvolts. This observation could be due to the fact that in the voluntary process the muscles for swallow initiation may not be as relaxed as in the swallow to command process task, and they may have already started to work towards swallow initiation before the swallow actually commences.[9] This tensing and contracting of muscle groups to prepare for the impending swallow could increase muscle activity accounting for the increased baseline scores. This preparation for swallow would not necessarily be seen in a swallow to command process since the patient is focused on relaxing and waiting until they hear the command to swallow.

This observation also presents a limitation to this study in consistently choosing and recording baseline scores. Although procedures were standardized, there is some variability in knowing when to record a baseline score. Since muscle activity is constantly fluctuating, the investigators chose to record a baseline score when it paused for one second in the swallow to command setting and to select the baseline score at the moment the patient tapped the table in the voluntary setting. These procedures were used to control for potential variability involved in baseline measurements, and to have a standard time and procedure for recording baselines across all participants.

The variability between individual swallowing forces makes significant findings difficult to achieve in age comparisons. Significant findings are also difficult to achieve with healthy participants and with a younger elderly adult group (Group 2). Due to this variability, groups were compacted for comparisons of volume. No significant differences were found in the analysis of the different volumes of water swallowed. This shows that although the different processes are distinct in their elicitation of muscle force, different volumes do not affect the swallowing force.

However, changes in swallowing biomechanics such as the duration of airway closure[11] and PES opening have been demonstrated.[12]

Conclusion

This investigation provides a normative database of swallowing force using sEMG biofeedback. This database can be utilized by clinicians for comparison of their patients with swallowing disorders to participants with normal swallowing ability. This database utilizes two distinct age groups, two swallowing processes, three bolus sizes, and provides true ranges of swallowing force. The three main questions of this study were also answered by analysis of this database. First, there is no significant difference between the swallowing force of participants 18-25 years old and participants 60 years and older as measured by sEMG. Secondly, there is a significant increase in the amount of swallowing force elicited when patients are asked to swallow to command. This finding holds numerous implications for the processes used in swallowing therapy and assessment with sEMG biofeedback. And finally, there is no significant difference in swallowing force between the different volumes of water swallowed (5ml, 10ml, 20ml). Therefore clinicians could select varying bolus sizes in therapy knowing that maximum performance values will not be affected by bolus size.

Table 1: Normative Database of swallowing force using surface electromyography

		Avg. Baseline	Avg. Max	Minimum	Maximum	Mean	St. Dev
18-25 (Group1) Voluntary							
	5ml	5.02	11.51	2.5	26	6.49	3.98
	10ml	5.45	12.86	2.7	26	7.4	4.08
	20ml	6.13	12.74	4	27	7.04	4.1
60+ (Group 2) Voluntary							
	5ml	4.54	10.11	2	21	5.57	3.54
	10ml	5.56	10.77	2.2	20	5.2	3.54
	20ml	6.15	11.47	3.1	20	5.34	3.99
18-25 (Group 1) Command							
	5ml	3.01	10.49	1.6	20	7.48	2.92
	10ml	3.24	11.51	1.8	28	8.26	4.27
	20ml	4.11	12.62	2	34	8.52	4.97
60+(Group 2) Command							
	5ml	2.92	9.79	1.9	20	6.87	4.05
	10ml	3.36	10.36	1.6	32	7	5.28
	20ml	3.92	11.19	2	31	7.27	4.68

Table 1:

Avg. Baseline= Baseline measurements / # participants in group (n=30).

Avg. Max= Maximum Force measurements/# participants in group (n= 30).

Minimum= lowest recorded baseline measured in group for that volume.

Maximum= highest recorded maximum force measured in that group for that volume.

Mean= Average force calculated using Avg. baseline and Avg. Max.

St. Dev= Range of force measurements in the group from calculated mean.

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