Spring 2019

Participant accuracy and impact of biofeedback on a skilled swallowing task

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Participant Accuracy and Impact of Biofeedback on a Skilled Swallowing Task

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An Honors College Project Presented to

the Faculty of the Undergraduate

College of Health and Behavioral Studies

James Madison University

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Accepted by the faculty of the College of Health and Behavioral Studies, James Madison University, in partial fulfillment of the requirements for the Honors College.

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PUBLIC PRESENTATION

This work is accepted for presentations, in part or in full, at JMU Honors College Symposium on April 5, 2019.

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Acknowledgements

To Dr. Kamarunas- my primary thesis advisor- Thank you for trusting me to help with research in your lab. I knew next to nothing about the anatomy and physiology of swallowing before starting to work in your lab, but knew I wanted to have you as a mentor because you would keep your expectations high and challenge me. Finally, thank you for continuing to work with me even as exciting things were happening like growing your family!

To Rachel Rinehart- the mother of this original experiment- I have the utmost respect for what you did coming up with research questions, filling out IRB paperwork, running participants, and completing your project. I am so happy we were able to stay in touch as I continued to look at and analyze your data. Without you, this project would not exist. Best of luck to you as you officially become a Speech Language Pathologist!

To Dr. Temple- my inspirational reader- You showed me what a passion for research looks like and encouraged me to go out of my comfort zone. You mentored me through my first research paper and presentations. I am so glad you were able to support me throughout this research process as well. Thank you for being a role model. I will always remember you, DT!

To Dr. Gray- my Honors CSD Advisor- When I came into your office and told you what I was interested, you shared about how the sky is the limit for opportunities in our field. I am excited to continue exploring those opportunities. Ultimately, thank you for connecting me with Dr. K to complete this Capstone Project.

To my family & friends- my trustworthy cheerleaders- You have heard about this project for nearly two years and have consistently supported me even if you never understood what "dysphagia" meant. You let me stare at your throats while we ate lunch out of habit after coming out of the lab. Thank you for celebrating this accomplishment with me!

This project was presented at the Honors Symposium on April 5, 2019 hosted by the James Madison University Honors College at Hotel Madison. Thank you to Dr. Newcomer, Dr. Frana, Jared Deiner, Tammy Steele, and Dianne Folk for all you did to help set that up.

ABSTRACT

Biofeedback is as a visual way to self-assess muscle contraction, particularly during rehabilitative exercises. Speech language pathologists and otolaryngologists have investigated the use of visual biofeedback in swallowing therapy, especially for volitional swallowing rehabilitative exercises such as the effortful swallow, which requires the patient to maximally swallow with all their strength. In contrast to the effortful swallow, "effortful skilled swallowing" is the ability to swallow with a specific and precise amount of effort, which is an emerging topic in dysphagia research. Dysphagia, also known as disordered swallowing, can be an organic congenital disorder treated via feeding tubes, or an acquired disorder as a result of a old age, traumatic injury, intubation, neurodegenerative diseases, or a stroke, among other etiologies. In the United States, one quarter of the population will struggle with swallowing at some point. It plagues 13-15% of acute care hospital patients, 30-35% of those in rehabilitation settings, and 40-50% of individuals living in nursing homes. This study examined the use of skilled swallowing targets in healthy, non-dysphagic participants, concentrating on examining the following: 1) the participants' ability to differentiate and execute different skill level targets, 2) the effectiveness of visual biofeedback at improving participant's accuracy at skilled swallowing tasks, and 3) participant accuracy over time, over the course of 30 successive swallows. Data was collected from eight participants, seven of which were used in this study. Participants were trained and then randomly instructed to swallow at three different effort levels: 50%, 75%, and 100%. They were then evaluated to see how closely they swallowed compared to the target effort level. This was defined as the level of accuracy. Accuracy was measured by surface electromyography (sEMG) electrodes placed on the anterior submental region of the neck. Visual biofeedback of their EMG signal was provided to the participant for fifteen random

swallows of the thirty swallows in each experimental exercise. The results indicate that participants are able to modulate their swallowing effort to approximate three different effort levels, but that biofeedback did not affect participants' accuracy. Additionally, participants' accuracy in achieving skilled swallow targets did not change over the course of 30 swallows. These results indicate that swallowing effort can be modulated and used as a skilled task during treatment. Biofeedback, while useful in training a swallowing task, may not be needed during every trial to ensure accuracy. Finally, in these healthy participants, there did not seem to be an effect of boredom or fatigue while successively performing 30 skilled swallow tasks over the course of 22 minutes. It is not known if these results are generalizable to an older, dysphagic population.

LITERATURE REVIEW

The aim of this study is to improve the knowledge of swallowing rehabilitation to help treat dysphagia, or difficulty swallowing. Immediate consequences of dysphagia include aspiration and choking, which can be life threatening. If an individual aspirates, food or liquid can enter the lungs, causing pneumonia. Furthermore, individuals with dysphagia can be apprehensive about eating or drinking, leading to dehydration or malnutrition (Foley, Martin, Salter, & Teasell, 2009). Socially, eating and swallowing are key components of daily living and relationship building, and therefore dysphagia potentially reduces one's quality of life (Foley et al., 2009).

Physiologically, oropharyngeal dysphagia is a result of a neurological impairment or impairment with the oropharyngeal tract. While in the past people have accepted that swallowing is a reflexive process and have looked for other methods of nutritional intake, there is now evidence that behavioral training can impact swallowing (Malloy, Valentin, Hands, Stevens, Langmore et al., 2014). Many oropharyngeal muscles, including the suprahyoid and pharyngeal constrictor muscles, are involved in the swallowing process. The strength of muscle contractions denotes the strength of the swallow. Several compensatory strategies and therapy exercises have been developed to strengthen these muscles and reteach neural behaviors including using increased effort while swallowing, which is called the effortful swallowing exercise (Clark & Shelton, 2014).

Previous research indicates that we swallow using submaximal effort, indicating there is greater muscular potential and reserve in the system (Huckabee, Butler, Barclay, & Jit, 2005; Huckabee & Steele, 2006; Wheeler-Hegland, Rosenbek, & Sapienza, 2008). A normal swallow uses approximately 42-53% maximal submental muscle contraction as measured by sEMG

(Huckabee et al., 2005; Wheeler-Hegland & Rosenbek, 2008). Therefore, extra muscle contraction or effort could be utilized as a strength building technique in swallowing rehabilitation. An effortful swallow requires increased intraoral pressure by retracting the tongue posteriorly and elevating the posterior pharyngeal wall (Fukuoka, Ono, Hori, Tamine, Nozaki et al., 2013). The propulsive force of the tongue in an effortful swallow is four times the amount of force of a normal swallow (Pouderoux & Kahrilas, 1995). Additionally, velopharyngeal, mid-hypopharyngeal, and upper esophageal sphincter pressures increase with effortful swallows (Takasaki, Umeki, Hara, Kumagami, & Takahashi , 2011). The increase in pressure immediately results in decreased pharyngeal residue, which reduces the patient's risk of penetration or aspiration (Fukuoka et al., 2013). For this reason, dysphagia rehabilitation utilizes effortful swallows as a therapy exercise to potentially increase floor of mouth (FOM) and pharyngeal muscular contractions long term (Doeltgen, Ong, Scholten, Cock, & Omari, 2017).

Several studies have shown that the effortful swallow improves movement and pressure during swallowing in healthy individuals, which would help to protect the airway from post swallow residue, but this may not be generalizable to all dysphagic populations. Importantly, one study demonstrated that four of eight participants with histories of pharyngeal dysfunction were not able to produce an effortful swallow (Burlow, Olsson, & Ekberg, 2001). However, this same study reported that while dysphagic participants still experienced penetration after performing effortful swallowing exercises, the depth of penetration into the larynx and trachea decreased (Burlow et al., 2001). There are contradictory findings on whether the effortful swallow increases swallow pressure or duration compared to a regular swallow in dysphagic individuals (Burlow, Olsson, & Ekberg, 2002; Lazarus, Logemann, Song, Rademaker, & Kahrilas 2002). These discrepancies could be due to the etiology of swallowing difficulties individuals had and the specific focuses of each research study. Five out of six individuals who were taught how to perform an effortful swallow in treatment showed enough physiologic improvement to have their feeding tubes removed (Crary, 1995). While this is a start, there is not extensive research at this time about the efficacy of the effortful swallowing exercise used as an isolated rehabilitative technique to improve pathophysiology.

There are several research studies examining various skilled swallowing exercises, exercises with specific targets that require neurological motor planning to achieve, as treatment for individuals affected by dysphagia in heterogeneous populations. The McNeil Dysphagia Therapy Program (MDTP) utilizes a combination of strength and skill exercises through a hierarchy of boluses as rehabilitation treatment for 15 one hour sessions over the course of 3 weeks (Lan, Ohkubo, Berretin-Felix, Sia, Carnaby-Mann, et al., 2012; Crary, Carnaby, LaGorio, & Carvajal 2012). In three research studies, a combined 25 out of 25 individuals with dysphagia who underwent the MDTP had an increase in post-therapy success for swallowing thin liquids (Sia, Carvajal, Lacy, Carnaby, & Crary, 2015). In a different study, mixed strength and accuracy swallowing training was used in therapy over 11-12 weeks for six patients with dysphagia (Steele, Bailey, Polacco, Hori, Molfenter, et al., 2013). While five out of six of them had improved scores on the penetration aspiration scale in response to thin liquids, the same percentage reported worsened pharyngeal residue after the treatment (Steele, et al., 2013). Recent research on dysphagia rehabilitation points to the positive impact of skilled exercises in treatment because it targets neurological executive swallowing functioning, while strength exercises target muscle motor weakness (Huckabee & Burnip, 2018). Skilled swallowing tasks have been found to heighten cortical awareness and improve swallowing speed of patients with Parkinson's Disease (Athukorala, Jones, Sella, & Huckabee, 2014). Athukorala's study also used biofeedback to guide participants in meeting their skilled target percentage of 50% of their average maximum swallowing ability. Skill-based training has also been used to train patients to use an optimal respiratory-swallow pattern for improved swallowing performance (Martin-Harris, McFarland, Hill, Strange, Focht, et al., 2015). Although research on skill training vs. strength training is just emerging, the integration of motor learning approaches through skilled exercises into dysphagia rehabilitation has significant potential.

Swallowing can be an abstract concept to some people because it is an internal and often subconscious process. Therefore, individuals with oropharyngeal dysphagia may not be able to sense the strength of their swallows. Biofeedback refers to the visual or auditory signals produced by physiological information like pharyngeal muscle contraction (Li, Wang, Lee, Wang, Shieh et al., 2016). Biofeedback engages the patient in an active process of training, as opposed to a passive treatment, that works to purposefully control automatic responses. The goal of biofeedback in therapy is that the oropharyngeal muscles will be strengthened and habituated into a coordinated, strong swallow. In addition to physiological muscular feedback, it also has proven to accelerate learning and retention in drills that exercise executive functioning skills to neurologically plan swallows (Crary, 2012; Wilkinson, Steele, Moosgagian, Zimmerman, Keisler, et al., 2015). While we know that biofeedback is used to develop better swallow outcomes in therapy (Humbert & Joel, 2012), this study uses biofeedback as a visual aid in self-monitoring swallowing to examine if it helps participants improve task accuracy.

In light of the ever-pressing need for evidence-based therapy approaches to help patients with dysphagia, this study aims preliminarily at investigating the following questions:

1. Are nondysphagic participants able to modulate their swallowing effort accurately during skilled swallow execution (50%, 75%, 100% effort)?

2. Does biofeedback affect accuracy in skilled effortful swallowing in nondysphagic participants?
3. Does accuracy in a skilled swallow task change over the course of 30 repetitions in nondysphagic participants?

METHODOLOGY

The data used in this research study had already been collected by Rachel Rinehart at James Madison University in her Honors Capstone Project submitted in the Spring of 2017 (Rinehart, 2017). She got approval from the James Madison University Internal Review Board (#16-0574). The researchers are comfortable and knowledgeable about what data was collected, how it was stored, and how to best utilize the software program. The data was organized by participant and swallow exercise.

Participants recruited from the James Madison University community had to be between the ages of 20 and 80 years old with no prior history of swallowing problems, neurological disorders, neck injuries, respiratory diseases, or psychiatric disorders other than medically managed depression. The Mini-Mental State Exam, Reflux Symptom Index, and Edinburgh Handedness Survey were used as screeners. Finally, the participants could not have open head wounds or vision deficits. Data was collected from eight participants, but only seven participants are included in this analysis due to equipment error (n= 50.83 years old, male=2, female=5. They all passed the Mini-Mental State Exam with a score above 25, indicating they were cognitively able to understand and follow directions adequately and scored below 20 on the Reflux Symptom Index (RSI) denoting they did not have reflux disease that might affect their swallowing. They participated in the experiment for 3.5-4 hours on the fifth floor of the College of Health and Behavioral Sciences building at James Madison University in Dr. Erin Kamarunas' Neural Bases of Communication and Swallowing Lab at the Department of Communication Sciences and Disorders. The participants were trained in two swallowing exercises for the original study, the effortful swallow and the Mendelsohn maneuver. The Mendelsohn maneuver data was not analyzed for the purposes of this study. Each participant received training on how to complete the swallow exercises until they performed each correctly three to five consecutive times with and without biofeedback. The swallows were cued by a power point on a screen in front of the participant that signaled a new swallow approximately every 42 seconds. The participant received 5 ml of water via tubing on a water pump to swallow in the manner indicated by the cue. For the skilled effortful swallowing exercises, three different illustrations denote what level swallow to aim for and the researchers communicated that each illustration indicated a 50%, 75% or 100% swallow effort, depending on the height of the muscle contraction signal (Figure 1). Half of the swallows included visual biofeedback. The order was randomized within each participant and between participants. The personalized & dynamic visual biofeedback showing the strength of their swallow on an EMG graph was provided side by side with the Power Point visual of their target EMG. Participants could then compare their muscle contractions, shown on the EMG graph in real time, and increase or decrease their swallow strength to match the two graphs as close as possible. The skilled effortful swallow task was one of five tasks completed by the participant during the experiment, and included 30 swallows total over 22 minutes. The participant had the opportunity to take rests and use the restroom in between tasks.

Functional near infrared spectroscopy (fNIRS) probes were used to measure cortical activation during the tasks and was presented in Rachel Rinehart's thesis, but this data was not analyzed for this research project. Respiratory inductive plethysmography (Ambulatory Monitoring, Inc., Ardsley, NY, model 10.9000) monitors respiration via elastic bands around the chest and abdomen. Respiratory apnea, or cessation, indicates when a swallow starts and stops, and was used as confirmation of swallows. Piezoelectric accelerometer (Kistler Instrument Corporation, Amherst, NY, Model 8778A599) over the larynx was used as an indicator of laryngeal movement for swallowing to confirm swallowing. Surface electromyography electrodes (Teca electrodes; Nicolet Viking IV P) recorded suprahyoid and lingual muscle contractions. The electrodes were placed centrally in the submental region and adhered with medical tape (Figure 2). The sEMG data was also used to mark swallow onset and offset, as well as biofeedback for the participant during that portion of the experiment. The participants' lower face and neck were videoed and used when confirmation of swallowing was needed during off-line data analysis. All signals were synchronized and digitally recorded using Powerlab data acquisition system and Labchart 8 software (AD Instruments, Inc.).

For the purpose of this study, EMG signals were rectified and smoothed (Bartlett window). The EMG signal was then normalized to percentage. Max (100%) was defined as the highest single amplitude (in mV) during swallowing recorded during the task. The baseline, or 0%, was calculated by taking the average of at least ten sections of signal in which the participant was at rest (no movement). Therefore, the participants and researchers were able to see the participant's muscle contraction in terms of percentage of effort during and after the experiment, and the participant used this personalized information during the biofeedback swallows to gauge how accurately they were hitting the cued target. The normalized EMG data was used for data analysis in this study (Figure 3).

To answer the first research question, the peak percentage of each EMG signal during skilled effortful swallowing was measured and compared to the intended target. For example, during a swallow in which the participant was cued to use 50% effort level, they may have actually swallowed using 60% of their maximum effort, for a difference of +10% effort. To answer the second research question, the accuracy of the skilled swallows that had biofeedback was compared to the accuracy of the swallows that did not have biofeedback. Finally, to address the third research question, the mean accuracy of the first five skilled swallows were compared to the mean accuracy of the last five skilled swallows, regardless of the intended target or the presence/absence of biofeedback.

STATISTICAL ANALYSIS

To examine whether or not participants are able to distinguish between skill level targets with the appropriate swallow effort, the mean percentage effort for each target level (50%, 75%, 100%) and whether or not biofeedback affected the accuracy, a 2x3 repeated measures ANOVA was used with an alpha level of .05. To determine if accuracy changes from the beginning of testing to the end of testing, the difference between the intended target (50%, 75%, 100%) and the actual effort level was compared for the first five swallows of the task and the last five swallows of the task using a paired sample t test and an alpha level of .05.

RESULTS

Table 1 presents the mean percentages and standard deviations for accuracy by target level and Table 2 represents the mean differences and standard deviations for swallows with and without biofeedback. Results indicate that participants were able to accurately differentiate between skill level targets ($F(2)=7.3$, $p<0.01$), but that there was no effect for biofeedback ($F(1)=.012$, $p=.92$). Post hoc tests indicate a significant difference between each target level (Table 1). There was no interaction between accuracy per target level and biofeedback ($F(2)=.99$, $p=.4$)

Table 1

Target level	**Actual Percentage Effort Used** Mean % (SD)	**Post hoc testing alpha levels**
50%	61.5% (19.9)	50% vs 75%: $p=.013$; 50% vs 100%: $p=.002$
75%	75.1% (17.9)	75% vs 100%: $p=.016$
100%	84.3% (19.39)	

Table 2

Difference between Actual Swallowing Target and Percentage Effort Used by Participants with and without Biofeedback; Mean % (SD)	
With Biofeedback	Without Biofeedback
-1.3% (21.6)	-1.9% (22.4)

Table 3 presents the mean differences for the first and the last five swallows of the task. No significant difference was found for the accuracy of these two time groupings ($t(6)=.11$, $p=.92$).

Table 3

Difference between Actual Swallowing Target and Percentage Effort Used by Participants (means, SD) at the Beginning and End of Trials

First 5 Swallows	Last 5 Swallows
-1.4% (21.5)	-2.1% (19.2)

DISCUSSION

Skilled rehabilitation tasks in the field of dysphagia are only just emerging. It is important to establish that people are capable of distinguishing between different skilled targets and accomplishing the intended target that a therapist may ask them to do. This study indicates that people are able to conceptualize that they can swallow with different effortful levels and accurately achieve the intended target. This study only tested three different target levels, one of which is close to previously reported norms for normal swallow effort (42-53%) (Huckabee et al., 2005; Wheeler-Hegland & Rosenbek, 2008). It is not known if three levels are enough to fully engage the neuromuscular network for rehabilitation purposes or if people are capable of achieving accuracy at greater precision given more training (e.g. less distinction between levels, using 10% instead of 25%, for example).

Interestingly, biofeedback did not affect accuracy on skilled swallow targets in this study. It is possible that there are confounders to this finding. Firstly, the participants were all trained to the task using biofeedback and it is possible that once a paradigm was established in the participant's mind for what each effort level required, the biofeedback was no longer essential to accomplishing this. Additionally, the presence of biofeedback was randomly present/absent throughout the task. It is possible that intermittent biofeedback was enough to guide the participants' performances so that when biofeedback was not present, they were able to continue with those trials with relatively the same accuracy.

Previous work done in the lab has indicated that cortical activation, primarily in the sensory areas of the cortex, is greater when utilizing biofeedback during swallowing compared to swallowing without biofeedback (Rinehart, 2017). Interestingly, this difference in activation was not significant in the motor or premotor regions. As biofeedback did not improve accuracy to task, perhaps this cortical activation difference represents sensory and/or self-awareness of the swallowing structures rather than motor output.

It was considered that asking a participant to complete 30 repetitions of a task may be tedious and boring or that they may fatigue over time. Alternatively, the chance to practice 30 times in succession may improve their ability to complete the task over time. Therefore, we examined participant accuracy at the beginning of the task compared to the end, but found no differences. It is possible that a healthy, nondysphagic participant group, such as tested in this study, is less likely to feel fatigue after 30 swallows, but that this may be an issue in the populations that would be completing swallowing rehabilitation.

As this is an emerging topic in the field, the future directions are many. The most obvious is the application of this treatment technique in patients with dysphagia, such as patients with Parkinson's disease, CVA, and head & neck cancer. These groups generally all have different mental capacities and therefore could have different abilities to respond to the stimulus. Skilled swallowing tasks should be compared to strength swallowing task (completing maximal effort repetitions only) in patients with different swallowing impairment profiles to determine which exercise type is best with specific kinds of swallowing problems. A more in depth study on how many swallows an individual would have to do before fatigue sets in would also be beneficial for creating treatment regimens.

LIMITATIONS

First, this study has a small sample size (n=7) of healthy participants. A larger sample would provide more accurate results and would be more generalizable if completed on patients with dysphagia. Secondly, we used surface submental EMG as a measure of swallowing strength as it is non-invasive and easy to record. However, there is no proven association between the contraction of the submental muscles and internal pharyngeal pressures (Huckabee et al., 2005), as submental muscle contraction can be highly variable even within the same participant. Therefore, it is not known if this measure is the best for training participants to this task, but rather was used because it is a measure well represented in the literature and is a measure of convenience (non-invasive). Lastly, although the participants did receive task training prior to the experiment, the training was short for the sake of time. They were required to demonstrate accuracy to task on 3-5 consecutive swallows prior to beginning, which required different lengths of time and practice for different participants and this was not standardized so as to replicate what may happen in a real clinical situation. However, there did not seem to be a practice effect in this study as performance did not improve from the beginning of the task to the end.

CONCLUSION

This study looked at three different research questions centered around skilled swallow tasks and biofeedback in healthy, nondysphagic people. Participants are able to complete skilled swallow tasks in which they are required to swallow at incremental effort levels and they are able to do this relatively accurately. Biofeedback may not be needed for every swallow during consecutive skilled swallow tasks, but may be needed for training the skilled task. Biofeedback may or may not be needed incrementally during the session to maintain accuracy, this study did not examine this question. Thirty skilled swallows did not cause mental or physical fatigue that affected accuracy during this experiment.

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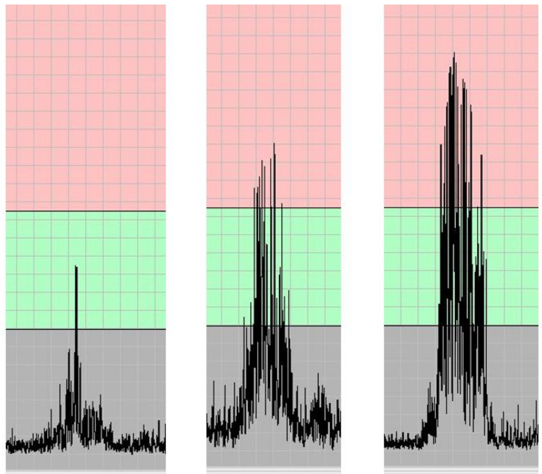
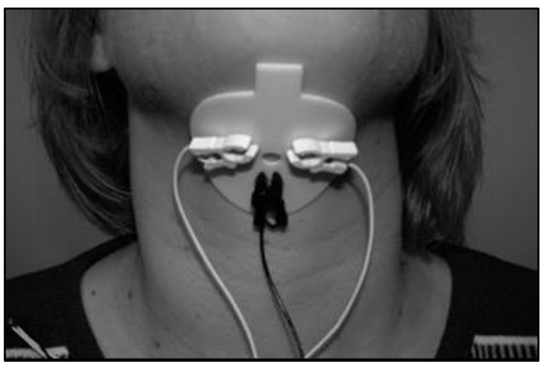
FIGURES

Figure 1. Power Point slides used to cue skilled swallowing target levels.



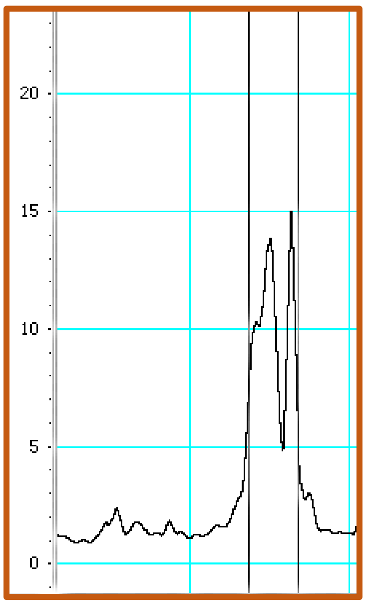
50% 75% 100%

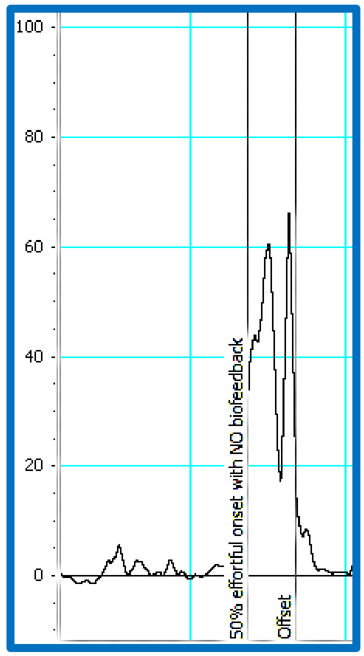
Figure 2. Submental electrode placement.



"Biomedical correlates of surface electromyography signals obtained during swallowing by healthy adults," by M.A. Crary, G. D. Cardaby Mann, and M. E. Groher, 2006, Journal of Speech, Language, and Hearing Research 49, p. 189

Figure 3. Skilled Effortful Data Example from Participant 301. The orange graph on the left shows a swallow (x-axis= time, y-axis=mV). The blue graph to the right shows the same swallow after individualizing the participant's swallowing percentage (0%= 1.211 mV, 100%=22.096 mV).





mV **%**