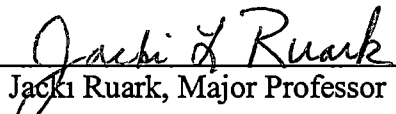
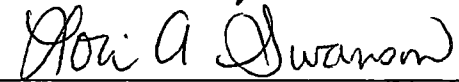


To the Graduate Council:

I am submitting herewith a thesis written by Joy A. Will entitled "The Effects of Bolus Volume and Consistency on Amplitude and Duration of Muscle Activity During Swallowing in Adults". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Speech Pathology.


Dr. Jacki Ruark, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Associate Vice Provost and Dean of
The Graduate School

The Effects of Bolus Volume and Consistency on
Amplitude and Duration of Muscle Activity During Swallowing in Adults

A Thesis
Presented for the
Master of Arts Degree
The University of Tennessee, Knoxville

Joy Allison Will
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Abstract

Results of this investigation support previous studies which found that bolus volume and consistency significantly affect average duration and amplitude of muscle activity during swallowing in adults. Electromyographic (EMG) activity from submental (SM) and laryngeal strap muscles (LSM) was recorded as participants swallowed boluses that varied in volume and consistency. Participants in this study included ten adult females (mean age = 22.6 years). Methodological differences between this study and previous physiologic investigations included the use of six different food and barium consistencies (water, pudding, cheese paste, Cheerios®, barium liquid and barium paste) in addition to five different bolus volumes (1, 3, 5, 10, and 20 ml).

Regarding bolus consistency, findings of this investigation indicated that average duration of SM and LSM activity increased significantly when participants swallowed pudding, cheese paste and barium paste and Cheerios® when compared to water. For bolus volume, significant increases in average duration of SM and LSM activity occurred when participants swallowed boluses of 20 ml compared to boluses of 1 ml. Similarly, average amplitude of muscle activity during swallowing was significantly affected by bolus volume and consistency, however the effects of bolus consistency depended upon the muscle involved. Average amplitude of SM activity increased significantly when participants swallowed: 1) pudding, cheese paste, Cheerios®, barium liquid, and barium paste consistencies compared to water, 2) cheese paste only compared to water, and for barium paste compared to barium liquid. Average amplitude of LSM activity increased significantly when participants swallowed pudding, cheese paste and barium paste when

compared to water, and for swallows of thick paste compared to barium liquid.

Regarding bolus volume, significant increases in the average amplitude of SM and LSM activity occurred when participants swallowed boluses of 20 ml compared to boluses of 1, 3, and 5 ml.

Currently, bolus volume and consistency are not controlled or standardized when performing swallowing evaluations (as in a modified barium swallow study) or during treatment of swallowing disorders. Results of this investigation indicate that muscle activity is not consistent across volumes and consistencies presented in this study. These findings support the adoption of standardized measures for bolus volume and consistency for use during swallowing evaluations and in treatment of swallowing disorders.

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CHAPTER I

Introduction and Review of Literature

Introduction

Previous research on swallowing in adults indicates that variables such as bolus volume and consistency significantly affect the oral and pharyngeal stages of swallowing. From the existing data however, there are limited and conflicting results regarding these quantitative electrophysiologic effects. In adults, bolus volume and consistency may affect the amplitude as well as the duration of muscle activity. Quantitative information regarding the effects of bolus volume and consistency on muscle activity during swallowing is needed to aid in the effective evaluation and treatment of swallowing disorders.

Effects of Bolus Volume and Consistency on Aspects of Swallowing in Adults

Reimers-Neils, Logemann, and Larson (1994) conducted a study examining the effects of bolus consistency on total duration and average amplitude of muscle activity during swallowing. Using electromyography (EMG), activity of the submental (SM) and infrahyoid (IH) muscle complexes of five normal volunteers (one male and four females) was recorded during swallowing. Three different food consistencies (thin liquid, thin paste, and thick paste) were presented. The volume of the boluses was held constant at 3 milliliters (ml). Results of this study indicated that the total swallow duration increased significantly across consistencies (from liquid and thin paste to thick paste consistencies). Average amplitude of SM EMG activity increased significantly for swallows of thick paste compared to swallows of thin liquid and thin paste. Additionally, amplitude of IH muscle activity demonstrated effects similar to those observed for SM activity.

However, no results were reported for thin versus thick pastes (Reimers-Neils et al., 1994).

In an investigation of swallowing activity using EMG, Ruark, Peters, and McCullough (1999) examined the effects of changes in bolus consistency on average amplitude and duration of muscle activity during swallowing in children and adults. This study involved ten typically developing five-year-old females, ten typically developing eight-year-old females, and ten young adult females. Bi-polar surface electrodes were placed at four target sites including the right upper lip (RUL), the right lower lip (RLL), the submental area (SM), and the laryngeal strap muscles (LSM, targeting the thyrohyoid). Participants were presented with five different food substances, including water, thickened liquid, pudding, cheese paste, and gummy bears. Bolus volume was held constant (3 ml of water, thickened liquid, pudding, and paste, and one gummy bear). Overall, the average duration of SM and LSM activity in the adults increased systematically across bolus consistencies. Results of an ANOVA for average duration of muscle activity revealed significant interactions between muscle and consistency for both children and adults. Post-hoc analyses revealed that average duration of SM activity increased significantly for swallows of cheese paste compared to swallows of water. Significant increases in average duration of LSM activity occurred for swallows of pudding and cheese paste versus water, and cheese paste versus gummy bears (Ruark et al., 1999)

In regard to average amplitude of muscle activity, statistical analyses revealed a significant main effect for bolus consistency. Specifically, swallows of cheese paste produced significantly greater EMG amplitudes than other consistencies (water, thickened liquid, pudding and gummy bears). In addition, average amplitude of muscle activity was significantly greater during swallows of gummy bears compared to swallows of water.

Additional studies have examined the effects of bolus volume on muscle coordination during swallowing in conjunction with bolus consistency. Dantas and Dodds (1990) conducted a study of the effects of bolus volume and consistency on the magnitude (amplitude) and duration of SM and IH EMG activity, hyoid movement, and bolus transit through the mouth and pharynx. The study included nine healthy adult males. Each participant swallowed various volumes (2, 5, 10, and 20 ml) of barium liquid and barium paste. Swallowing activity was quantified via videofluoroscopy and electromyography. The results of the study indicated that bolus volume did not alter the duration or amplitude of SM and IH EMG activity for barium liquid or paste (Dantas & Dodds, 1990). Regarding the effects of bolus consistency, average normalized amplitude of SM and IH activity during swallowing increased significantly for swallows of barium paste compared to swallows of barium liquid, regardless of bolus volume. Additionally, the average duration of SM and IH muscle activity during swallowing increased significantly for swallows of barium paste compared to swallows of barium liquid. The researchers concluded from the results of this study that while bolus volume did not affect

SM or IH EMG activity, bolus consistency (barium paste versus barium liquid) significantly affected the average amplitude and duration of muscle activity during swallowing.

In a similar study, Dantas et al. (1989) studied the effects of bolus volume and consistency on the oral and pharyngeal phases of swallowing. This study combined videofluoroscopy, manometry, and SM EMG recordings for 2, 5, 10, and 20 ml of barium liquid and paste in 10 healthy adult males. The researchers found that increased bolus volume was caused an earlier onset of anterior tongue base movement, anterior laryngeal movement, and superior palatal movement, as well as earlier upper esophageal sphincter (UES) relaxation and opening. However, increases in bolus volume did not significantly affect the amplitude or duration of SM EMG activity. Results of the study also indicated that bolus consistency was directly related to the oral and pharyngeal transit time (transit times increased for barium paste versus liquid across all volumes; Dantas et al., 1989). As in the previously discussed study, only bolus consistency (barium paste versus barium liquid) was found to affect SM and IH muscle activity during swallowing.

Conflicting results regarding the effect of bolus volume on swallowing coordination were found in a study conducted by Ertekin et al (1997). SM and cricopharyngeal (CP) EMG were used to measure the effects of swallowing saliva (dry swallow), as well as 3, 10, and 20 ml of liquid (water) and semisolid (pudding) consistencies in 14 female and 11 male healthy volunteers. Contrary to the findings of previous studies examining the effects of bolus volume on muscle activity (Dantas &

Dodds, 1990; Dantas et al., 1989), the researchers found that the duration of SM EMG activity, as well as the average duration of CP EMG activity increased significantly as bolus volume increased from 3 to 20 ml of water. Furthermore, this study found the peak amplitude of SM EMG activity to be significantly higher during dry swallows than for swallows of 3, 10, or 20 ml of water (Ertekin et al., 1997). The researchers concluded that the apparent conflict between the results of this study and previous investigations (e.g., Dantas & Dodds, 1990; Dantas et al., 1989) examining the effect of bolus volume on swallowing may be attributed to the use of different textures (water and pudding versus barium liquid and paste).

Summary of Review of Literature

Studies examining the effects of bolus consistency on swallowing have consistently indicated that bolus consistency affects the amplitude and duration of muscle activity during swallowing. Reimers-Neils et al (1994) and Ruark et al. (1999) conducted investigations using EMG to examine the effects of bolus consistency on muscle activity during swallowing. For these investigations, bolus volume was held constant at 3 ml. Results indicated that bolus consistency significantly affected the amplitude and duration of muscle activity during swallowing (Reimers-Neils et al., 1994; Ruark et al., 1999).

Dantas and Dodds (1990) and Dantas et al. (1989) investigated the effects of bolus volume and consistency on muscle activity during swallowing. Results of these investigations found that the average amplitude of SM and IH muscle activity during

swallowing increased significantly for swallows of barium paste compared to barium liquid. Bolus volume was not found to significantly affect the amplitude or duration of muscle activity during swallowing.

Although previous studies found similar results regarding the effects of bolus consistency on swallowing coordination, the literature is mixed with regard to the effects of bolus volume on duration and amplitude of muscle activity during swallowing. Results from two studies (Dantas & Dodds, 1990; Dantas et al., 1989) using EMG to quantify muscle activity during swallowing indicated that bolus volume had no effect on muscle activity during swallowing. Conflicting results regarding the effects of bolus volume on the amplitude and duration of muscle activity were obtained from a third study (Ertekin et al., 1997). These results revealed that bolus volume significantly affected the duration of muscle activity during swallowing. However, methodological differences exist between these studies (water and pudding consistencies versus barium liquid and paste).

Purpose of Study and Research Questions

The purpose of this study was to compile quantitative, normative data for adult females with regard to the effects of various bolus volumes with changes in consistency on the average duration and amplitude of submental and laryngeal EMG activity during swallowing.

This study investigated the following:

- (1) Does bolus volume influence the average duration of SM and LSM EMG activity during swallowing in adults?
- (2) Does bolus volume influence the average amplitude of SM and LSM EMG activity during swallowing in adults?
- (3) Does bolus consistency influence the average duration of SM and LSM EMG activity during swallowing in adults?
- (4) Does bolus consistency influence the average amplitude of SM and LSM EMG activity during swallowing in adults?

CHAPTER II

Method

Participants

Ten adult females 22-25 years of age (mean age = 22.6 years) served as participants for this study. Only female participants were included in order to control for any possible effects of gender differences on swallowing. Participants were undergraduate and graduate students in speech-language pathology at the University of Tennessee, Knoxville. Participants in this investigation received extra credit toward a class related to the study. Each participant completed one experimental session, which was approximately one hour in length.

Selection Criteria

Each participant completed a Participant Information Sheet (see Appendix A) to ensure normal feeding history and a lack of neurological impairment. Participants were free of any allergy or sinus-related congestion or upper respiratory infection at the time of the study.

Screening Tasks

Screening tasks were administered prior to the experimental session. These screening tasks ensured that all potential participants met the selection criteria for appropriate swallow pattern, cranial nerve function, and normal oral mechanism structure and function. Each participant was examined by a graduate student in speech-language

pathology with the supervision of a certified speech-language pathologist in order to verify the inclusionary criteria.

Screening for Normal Swallow

All participants were screened for normal swallowing patterns. Each participant was observed while swallowing a sip of water from a cup. The investigator observed the participant for evidence of an abnormal swallowing pattern (e.g., tongue protrusion during initiation of the swallow). In addition, the swallow was timed by palpating the submental and laryngeal area to feel for initiation and completion of tongue movement and laryngeal elevation. Participants were determined to have a normal swallow if the entire swallowing sequence occurred within approximately two seconds, via counting, and if the swallowing pattern was determined to be within normal limits.

Screening for Cranial Nerve Function

Each participant was given a cranial nerve screening. This screening was completed to ensure adequate functioning of cranial nerves V, VII, IX, X and XII (see Appendix B).

Screening for Normal Oral Mechanism

Each participant was given the Oral Speech Mechanism Screening Examination-Revised (St. Louis & Ruscello, 1987). This screening was completed in order to confirm that her oral mechanism was within normal limits for structure and function (see Appendix C).

EMG Recording Sites

Surface bipolar EMG recordings provided a comprehensive description of muscle activation patterns that occurred during swallowing and were obtained by a method that is minimally intrusive (Ruark & Moore, 1997). EMG records were obtained using Ag/AgCl disk electrodes (In Vivo Metrics, 4 mm outside diameter) filled with hypoallergenic electrode cream (Synapse Conductive Electrode Cream, Med-Tek/Synapse, Arcadia, CA) and were attached using adhesive electrode collars.

EMG activity was recorded from two sites: (1) submental area targeting the bilateral anterior belly of the digastric (SM) and (2) the right laryngeal strap muscle (LSM) targeting the thyrohyoid. Activity from other submental and laryngeal strap muscles may have been included in the recordings; however, these muscles are considered to be synergistic with the target muscles during swallowing.

EMG signals were amplified using Grass P511 physiologic preamplifiers (bandpass = 30-3000 kHz) and filtered at 500 Hz to prevent aliasing. All channels were recorded on a TEAC RD-2000 PCM DAT recorder for off line digitization and analysis. Channels were recorded in the following order:

- 1) FM audio recording of on-line descriptions of target behaviors by the principal investigator (Ms. Will),
- 2) submental muscle EMG activity,
- 3) right laryngeal strap muscles EMG activity,

- 4) FM audio recording of the sound spike obtained from the participant during the swallow, and
- 5) audio commentaries regarding ongoing changes in experimental conditions by investigator #2 (Dr. Jacki Ruark).

Electrode Placement

Each participant was seated at a small table after passing the screening tasks. Seating was arranged to minimize extraneous movement and possible entangling of the electrode wires. Before electrode placement, the investigator explained the study to the participant and obtained written and verbal consent (see Appendix D). The SM electrodes were placed immediately posterior to the mental symphysis, .5 cm apart and 1.5 cm from the body of the mandible (Green et al., 1997). The placement site of the SM electrodes was based on palpation of the main mass of the muscle as the participant opened her mouth. The LSM electrodes were placed .5 cm apart, perpendicular to one another, and 2 cm superior and lateral to the thyroid prominence. The placement site of these electrodes was based on palpation of the main mass of the muscle as the participant swallowed a sip of water. Prior to electrode placement, the participant's skin was scrubbed with alcohol gauze pads.

An investigator sat across from the participant at the table and elicited the target behaviors. The audio signals of the principal investigator were recorded using a wireless microphone attached to the shirt of the participant. EMG and audio signals were continuously recorded throughout the session.

Experimental Tasks

Each adult participant completed six experimental swallowing tasks composed of six different bolus consistencies. Each of the six tasks contained five volumes. These swallowing tasks were selected based on their potential to demonstrate varying effects in EMG amplitude and duration across bolus volumes and consistencies and are also comparable to tasks performed by adults in similar studies (Ertekin et al., 1997; Reimers-Neils et al., 1994). Four of the six swallowing tasks included various food consistencies, and two included barium consistencies. A practice swallow of 3 ml was completed prior to the initiation of swallowing trials for each consistency. The practice swallow allowed the participant to observe the consistency being presented and to become acclimated to the taste and texture before beginning the actual trials. Three swallowing trials were then completed for each of the five volumes (1, 3, 5, 10, and 20 ml) for each of the six consistencies, for a total of 96 swallows (90 experimental trials plus six practice swallows) per participant. Specifically, the swallowing tasks included:

- 1) water – measured volumes of water were presented in a paper cup,
- 2) Kraft® Handi Snacks Pudding, Kraft Foods, Rye Brook, NY – measured volumes of chocolate pudding were presented on a plastic spoon,
- 3) Nabisco® Easy Cheese, Nabisco Foods, Inc., East Hanover, NJ – measured volumes of cheese paste were presented on a plastic spoon,
- 4) Honey Nut Cheerios®, General Mills Sales, Inc., Minneapolis, MN – measured volumes of 1, 3, 5, or 10 Cheerios® were presented in a paper cup,

5) Liquid E-Z Paque® Barium, E-Z-EM, Inc., Westbury, NY – measured volumes of barium liquid diluted to 40% were placed on the anterior portion of the tongue using a syringe, and

6) Barium paste – paste prepared in the laboratory using 100 g of Smuckers® strawberry syrup added to 350 g of E-Z HD® barium sulfate, E-Z-EM, Inc., Westbury, NY, was measured and presented with a plastic spoon for 1, 3, and 5 ml boluses (a larger metal spoon was used to present the 10 and 20 ml boluses of paste).

Each participant was given specific instructions prior to each task (see Appendix E). The occurrence of each swallow was verified by the presence of a sound spike on an audio channel. The swallow sound was amplified and recorded by placing an amplified stethoscope (Luminaud Inc.) on the left laryngeal strap muscles, contralateral to the right LSM target area. If a participant refused a food item or a particular volume of an item, data from that participant was still included in the study.

Data Digitization

Target behaviors for each task were identified and parsed from the continuously taped experimental session and stored in separate files for subsequent digitization and analysis. EMG signals and the sound spike of each swallow were digitized at a rate of 1,000 samples/second per channel. Only target behaviors that were free of movement artifact or other unacceptable instances (e.g., 60-cycle line noise) were digitized. The two EMG channels and the swallow sound spike were digitized. The sound spike was used only for data verification and was not included in the data analyses.

Data Analysis

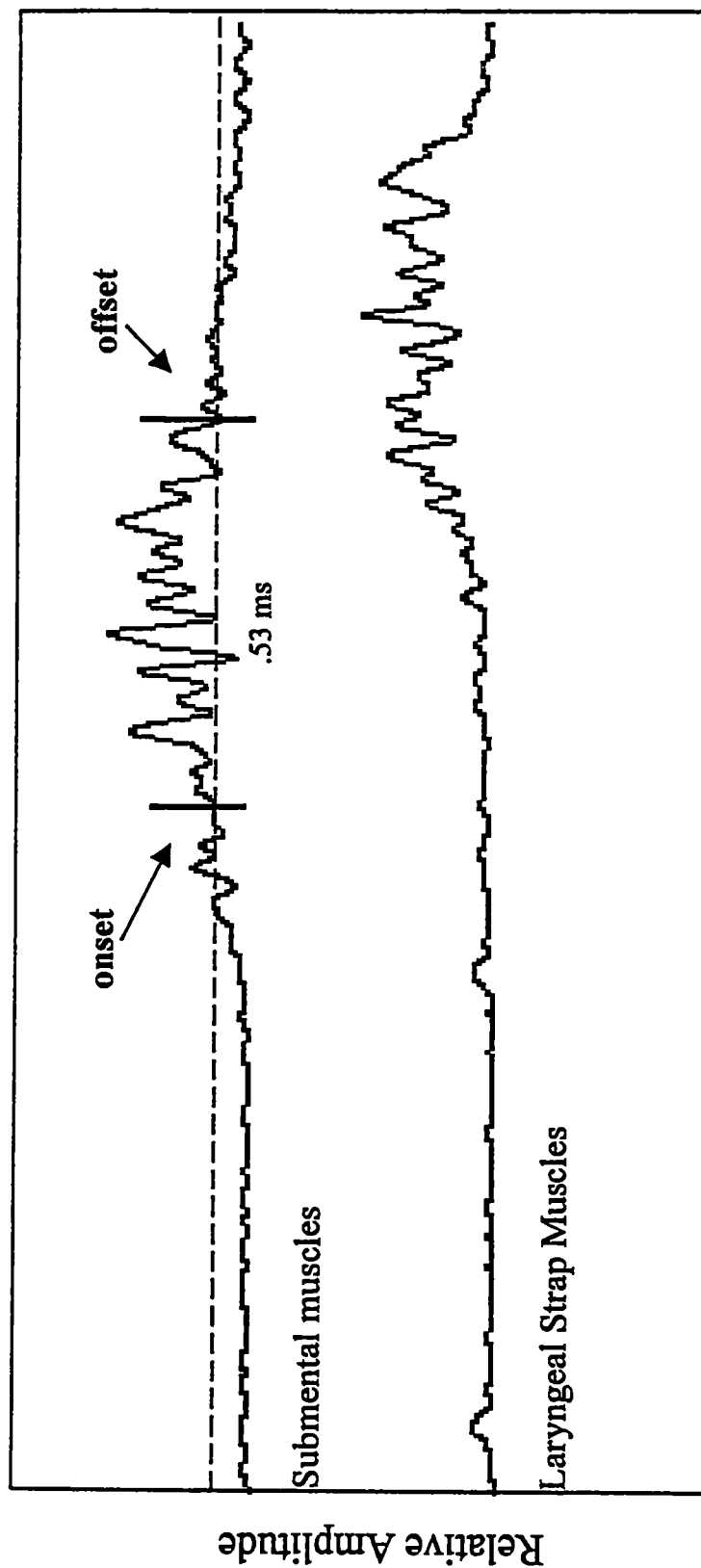
Two independent techniques were used to quantify swallowing as indicated by the EMG signals. Analyses of these data included measurements of the average amplitude and duration of EMG activity during swallowing across each volume and consistency. These measurements were obtained using algorithms custom designed for MATLAB (v.5.1; The Mathworks, Inc., 1999), a commercially available signal processing package.

Average Duration

This analysis encompassed automatic and computer-assisted identification of onset and offset of individual EMG bursts. Initially, the raw EMG data for the two signals were rectified and smoothed using an 8-pole Butterworth filter (low-pass cutoff 30 Hz). A custom-designed algorithm was used to assist in the identification of EMG onset and offset and low-level line noise. The algorithm computed and drew a line one SD above the lowest level (μV) of muscle activity for each channel. This line was used as a reference to help the investigator manually select EMG onset and offset for each burst. Figure 1 shows an example of the duration analysis used to calculate EMG onset and offset. The EMG signals shown in this figure were obtained from an adult as she swallowed 3 ml of water.

Average Amplitude

A custom-designed algorithm was used to calculate the average amplitude of each EMG signal. The raw EMG signals of the two muscles were displayed on the computer screen. After the algorithm demeaned, rectified, and filtered each signal, Ms. Will



Total time (1.7 sec)

Figure 1. Example of selecting EMG onset/offset for one swallowing trial using the duration analysis. Prior to this analysis, each EMG signal is first rectified and filtered as shown above.

placed a cursor immediately prior to the onset of EMG activity and immediately following the offset of EMG activity that occurred during the swallow. These two data points were previously determined via the durational analysis. The algorithm then calculated the cumulative sum of the area under the curve and then divided the sum by the time period of the selected data. The average EMG amplitude ($\mu\text{V} \times \text{sec/time}$) was obtained for each channel per task.

Percent Agreement

Percent agreement for data selection and analyses techniques for average EMG amplitude and duration was determined. For intrajudge agreement for data selection, Ms. Will transcribed and re-transcribed two complete data sets. Selected data that were within three seconds of the original transcribed data were considered to be in agreement. Intrajudge agreement for data selection was 97%. For interjudge agreement of data selection, two complete data sets were transcribed by a second graduate student and compared to the data selection of Ms. Will. Interjudge agreement was 95% for the data selection process. Ms. Will received training in data transcription from Dr. Jacki Ruark and through data transcription experience from a previous investigation. The second graduate student was trained in data transaction by Dr. Jacki Ruark.

Ms. Will analyzed and reanalyzed two complete data sets in order to determine intrajudge agreement for data analyses. For duration analyses, data that were within 500 ms of the original analyses were considered to be in agreement. Intrajudge agreement for duration analyses was 94%. For amplitude analyses, data that was within $.10 \mu\text{V}$ of the

original transcription was considered in agreement. Intrajudge reliability for amplitude data was 94% of the data. For interjudge agreement for data analyses, Ms. Will and Dr. Jacki Ruark each analyzed two specific files. Ms. Will compared her results, point by point, with those obtained by Dr. Jacki Ruark, and a mean percent agreement of 95% for duration and amplitude was determined. Ms. Will received training in data analysis from Dr. Jacki Ruark and through data analysis experience from a previous investigation.

Statistical Treatment and Analyses

For each participant, data analyses yielded a mean duration and mean average EMG amplitude for each task. Appendix F contains individual mean average duration values for each task. Appendix G contains the individual and normalized mean average amplitude values for each task. Prior to statistical analysis, the average amplitude values of each participant were normalized by dividing individual swallowing trials by the average amplitude value of SM activity for 20 ml of cheese paste. This particular trial was selected as it was predicted to produce the greatest amplitude of SM activity across participants. Specifically, the median SM value for 20 ml of cheese paste was calculated to equal 100% and all other swallowing trials within the participant were converted to a percentage of the original value. This procedure was previously used by Ruark and colleagues (1999) in a similar EMG study. ANOVAs for repeated measures and subsequent post-hoc analyses were performed to determine the effects of bolus volume and consistency on average duration and normalized amplitude of muscle activity during swallowing.

CHAPTER III

Results

This experiment was designed to determine if bolus volume and consistency affect the amplitude and duration of muscle activity during swallowing in adults. Mean normalized amplitude and duration values of EMG activity were compared within the group across bolus types and muscles

Data Set

All of the participants completed the experimental protocol. Each session lasted approximately one hour. Individual sessions involved six swallowing tasks, including the following consistencies: 1) water, 2) pudding, 3) cheese paste, 4) Cheerios®, 5) barium liquid, and 6) barium paste. For each of the six tasks, five different bolus volumes were presented (1, 3, 5, 10, and 20 ml). Participants were encouraged to swallow three trials of each volume for each of the six consistencies, for a total of 90 swallows per participant, plus the six practice trials. Of the 900 total swallows included in the experiment protocol, 890, or 98.8% of the trials were selected for analysis. Seven swallows were missing due to random participant refusal of particular consistencies, and three swallows were excluded due to data contamination (inability to identify the swallow from surrounding muscle activity).

Statistical Procedures

Three-way ANOVAs for repeated measures were used to test for mean differences in the average duration and normalized amplitude of muscle activity within the group

across tasks. Main effects and interactions identified by the ANOVA were further evaluated using post-hoc analyses (Tukey HSD procedure) to determine pairwise differences among tasks.

Average EMG Duration

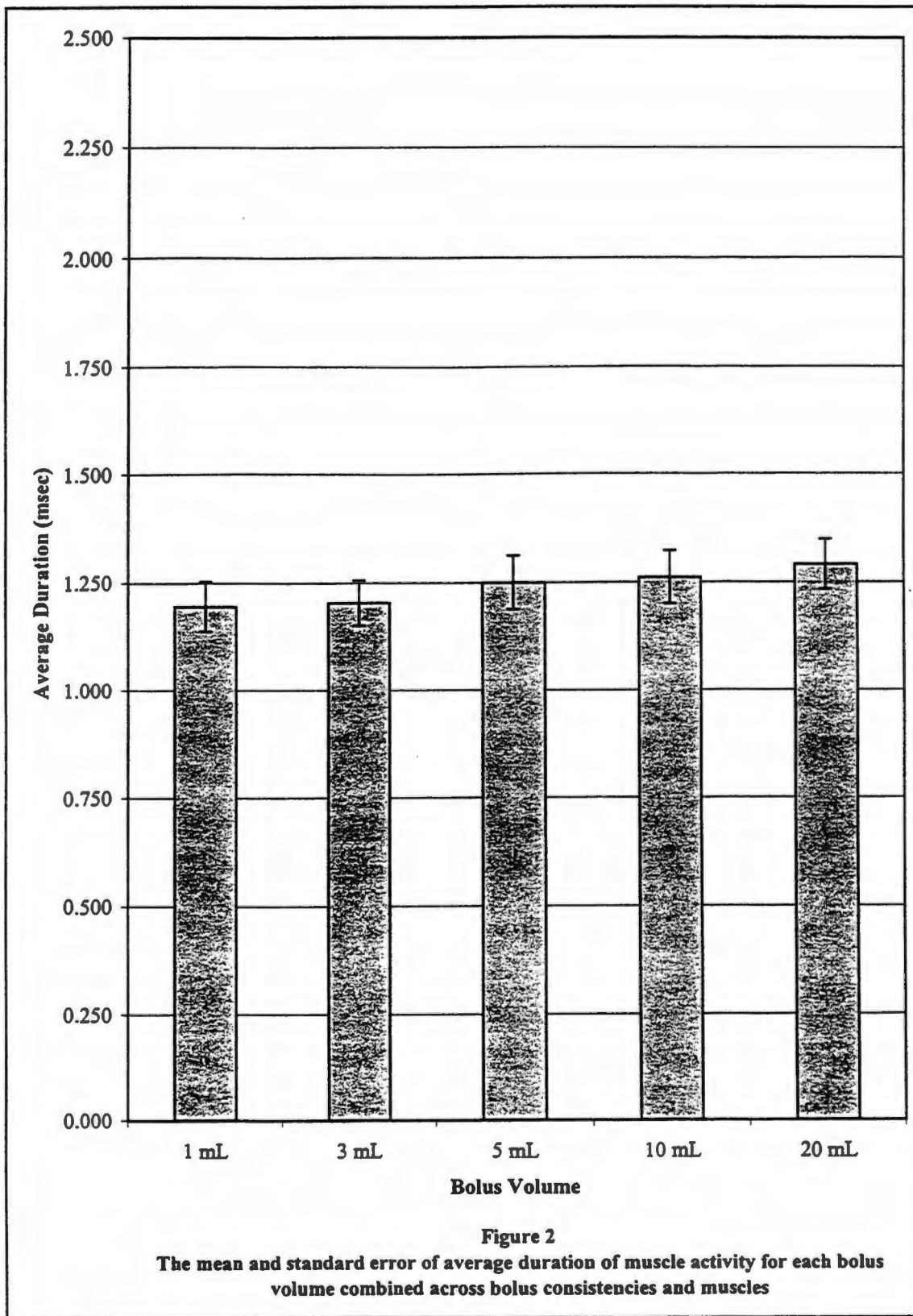
In order to facilitate comparisons of average duration of muscle activity during swallowing, the results from individual participants were combined to obtain a group average duration value for the five volumes of each consistency each muscle. Table 1 shows the group means and standard errors for the average duration of individual muscles, volumes, and consistencies for the group. Statistical analyses were performed using a three-way ANOVA for repeated measures. In order to correct for lack of sphericity in the covariance matrix, Huynh-Feldt correction was used, with a .05 alpha level. Results of the ANOVA revealed a significant main effect for both volume, $F(4, 36) = 5.118, p = .002$, and consistency $F(3.424, 30.813) = 8.145, p = .000$ (see Table 2). Tukey post-hoc analysis for bolus volume revealed that boluses of 20 ml yielded a significant increase in average duration of muscle activity when compared to boluses of 1 ml regardless of muscle or consistency (see Figure 2). Further analyses using pairwise comparisons for bolus consistency revealed a significant increase in average duration of muscle activity for boluses of pudding, cheese paste, Cheerios®, and barium paste when compared to boluses of water (see Figure 3)

Table 1. Group mean (in seconds) and standard error (SE) for average duration of muscle activity for boluses that vary by volume and consistency

SM	Mean	SE	LSM	Mean	SE
Water 1ml	0.989	0.05	Water 1ml	1.055	0.06
Water 3ml	0.977	0.05	Water 3ml	1.000	0.05
Water 5ml	1.066	0.07	Water 5ml	1.142	0.07
Water 10ml	1.036	0.06	Water 10ml	1.059	0.04
Water 20ml	1.060	0.05	Water 20ml	1.033	0.04
Pudding 1ml	1.223	0.03	Pudding 1ml	1.240	0.04
Pudding 3ml	1.254	0.05	Pudding 3ml	1.254	0.04
Pudding 5ml	1.228	0.06	Pudding 5ml	1.286	0.08
Pudding 10ml	1.296	0.08	Pudding 10ml	1.304	0.07
Pudding 20ml	1.285	0.05	Pudding 20ml	1.267	0.03
Cheese paste 1ml	1.266	0.07	Cheese paste 1ml	1.299	0.06
Cheese paste 3ml	1.198	0.08	Cheese paste 3ml	1.217	0.08
Cheese paste 5ml	1.227	0.04	Cheese paste 5ml	1.252	0.04
Cheese paste 10ml	1.291	0.06	Cheese paste 10ml	1.321	0.05
Cheese paste 20ml	1.328	0.05	Cheese paste 20ml	1.317	0.05
Cheerios 1ml	1.297	0.08	Cheerios 1ml	1.300	0.07
Cheerios 3ml	1.276	0.04	Cheerios 3ml	1.297	0.03
Cheerios 5ml	1.315	0.06	Cheerios 5ml	1.337	0.05
Cheerios 10ml	1.268	0.05	Cheerios 10ml	1.287	0.04
Cheerios 20ml	1.354	0.07	Cheerios 20ml	1.367	0.07
Barium Liquid 1ml	1.110	0.05	Barium Liquid 1ml	1.166	0.05
Barium Liquid 3ml	1.176	0.04	Barium Liquid 3ml	1.238	0.03
Barium Liquid 5ml	1.173	0.06	Barium Liquid 5ml	1.212	0.05
Barium Liquid 10ml	1.229	0.06	Barium Liquid 10ml	1.236	0.05
Barium Liquid 20ml	1.276	0.06	Barium Liquid 20ml	1.261	0.05
Barium Paste 1ml	1.183	0.07	Barium Paste 1ml	1.228	0.06
Barium Paste 3ml	1.265	0.07	Barium Paste 3ml	1.294	0.06
Barium Paste 5ml	1.372	0.08	Barium Paste 5ml	1.387	0.08
Barium Paste 10ml	1.421	0.09	Barium Paste 10ml	1.385	0.08
Barium Paste 20ml	1.484	0.08	Barium Paste 20ml	1.463	0.08

Table 2. ANOVA for average duration of EMG muscle activity

Effect	F Ratio	df	Error df	Significance
Muscle	2.999	1.000	9.000	0.117
Consistency	8.145	3.424	30.813	0.000
Volume	5.118	4.000	36.000	0.002
Muscle x Consistency	0.590	2.225	20.021	0.581
Consistency x Volume	0.964	11.396	102.568	0.485
Muscle x Volume	7.424	4.000	36.000	0.000
Muscle x Consistency x Volume	0.927	15.933	143.398	0.540



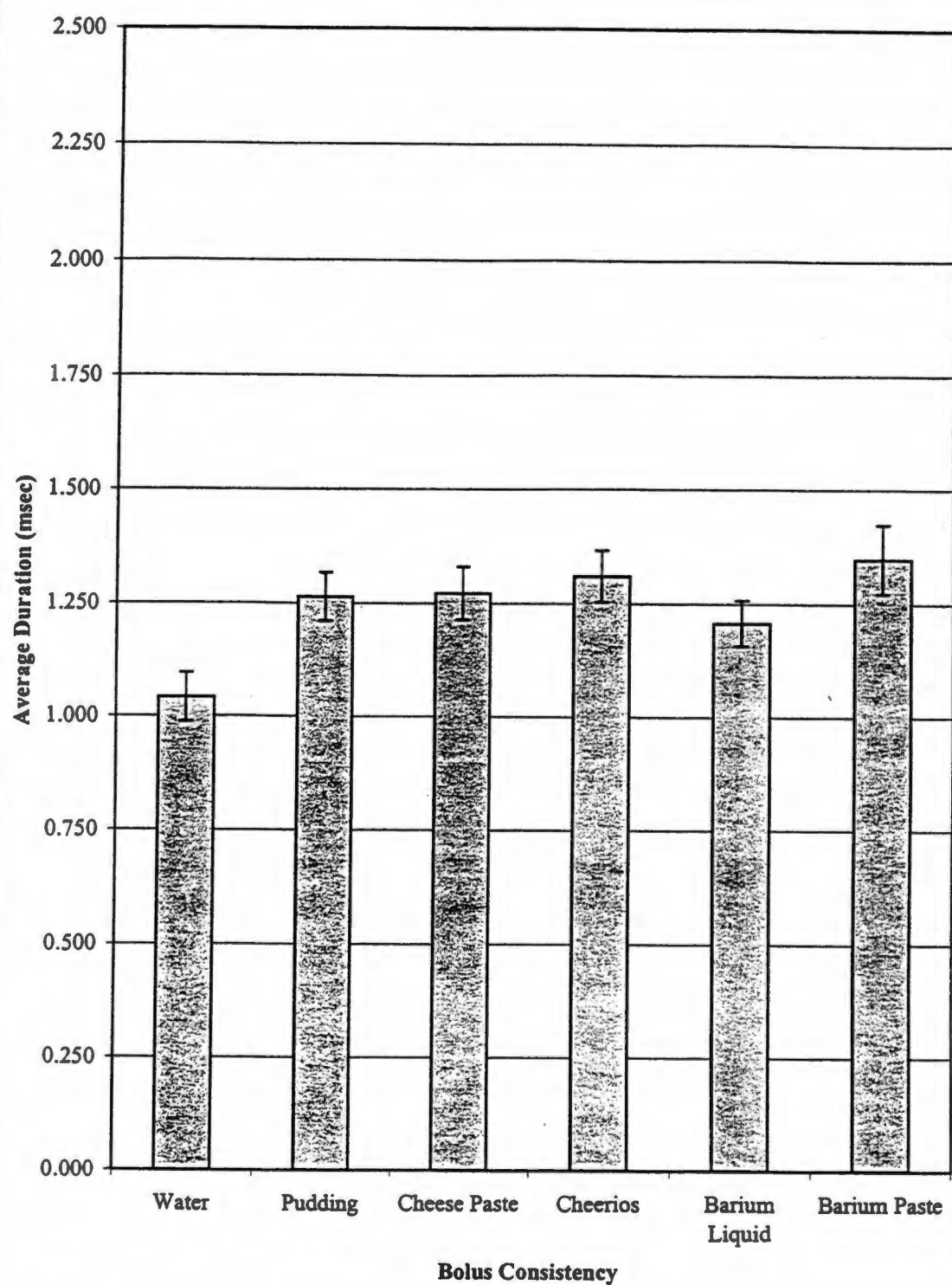


Figure 3
The mean and standard error of average duration of muscle activity for each bolus consistency combined across bolus volumes and muscles

Normalized EMG Amplitude

A mean normalized amplitude value was obtained for each participant for each of the five volumes of the six swallowing tasks. In order to facilitate comparisons of the average normalized amplitude of muscle activity, amplitude values of individual participants were combined to obtain a group average amplitude value for the five volumes of each consistency and for the SM and LSM muscles. Table 3 shows the group means and standard errors for the normalized amplitude values of the individual muscles, volumes and consistencies. Statistical analysis of the normalized amplitude values was performed using a three-way ANOVA for repeated measures. Significant main effects for volume, consistency, and muscle were identified (Huynh-Feldt correction procedure was used). Analysis of the data also revealed a significant interaction between muscle and consistency. Table 4 contains the findings of the three-way ANOVA. Post-hoc analysis (Tukey) for bolus volume revealed a significant increase in the normalized amplitude of muscle activity for swallows of 20 ml compared to swallows of 1, 3, and 5 ml, regardless of muscle or consistency (see Figure 4).

To further evaluate the interaction between muscle and consistency, one-way ANOVAs for repeated measures were performed to compare each muscle separately across consistencies. Results of the analyses determined that normalized amplitude of SM activity increased significantly for swallows of pudding, cheese paste, Cheerios®, barium liquid and barium paste when compared to boluses of water. In addition, normalized amplitude values for SM activity increased significantly for swallows

Table 3. Group mean (in uV) and standard error (SE) for average normalized amplitude of muscle activity for boluses that vary by volume and consistency

SM	Mean	SE	LSM	Mean	SE
Water 1ml	0.6021	0.04	Water 1ml	0.3854	0.03
Water 3ml	0.6002	0.05	Water 3ml	0.3808	0.02
Water 5ml	0.5778	0.04	Water 5ml	0.3767	0.01
Water 10ml	0.6275	0.06	Water 10ml	0.4069	0.02
Water 20ml	0.7024	0.05	Water 20ml	0.4637	0.02
Pudding 1ml	0.7993	0.04	Pudding 1ml	0.4505	0.04
Pudding 3ml	0.9258	0.06	Pudding 3ml	0.5134	0.04
Pudding 5ml	0.8705	0.05	Pudding 5ml	0.512	0.03
Pudding 10ml	0.894	0.07	Pudding 10ml	0.5274	0.05
Pudding 20ml	0.9787	0.07	Pudding 20ml	0.5821	0.04
Cheese paste 1ml	0.9719	0.05	Cheese paste 1ml	0.5063	0.03
Cheese paste 3ml	1.0068	0.08	Cheese paste 3ml	0.5528	0.05
Cheese paste 5ml	0.9992	0.07	Cheese paste 5ml	0.5529	0.04
Cheese paste 10ml	1.1116	0.05	Cheese paste 10ml	0.5832	0.04
Cheese paste 20ml	1.0153	0.01	Cheese paste 20ml	0.6469	0.04
Cheerios 1ml	0.9279	0.08	Cheerios 1ml	0.4925	0.05
Cheerios 3ml	1.0317	0.09	Cheerios 3ml	0.5111	0.05
Cheerios 5ml	1.0777	0.0012	Cheerios 5ml	0.5325	0.05
Cheerios 10ml	1.0398	0.00108	Cheerios 10ml	0.5557	0.07
Cheerios 20ml	1.0819	0.09	Cheerios 20ml	0.5865	0.06
Barium Liquid 1ml	0.7922	0.04	Barium Liquid 1ml	0.4678	0.05
Barium Liquid 3ml	0.8855	0.05	Barium Liquid 3ml	0.4739	0.04
Barium Liquid 5ml	0.8776	0.07	Barium Liquid 5ml	0.4646	0.04
Barium Liquid 10ml	0.8778	0.06	Barium Liquid 10ml	0.4809	0.04
Barium Liquid 20ml	0.9671	0.06	Barium Liquid 20ml	0.5523	0.04
Barium Paste 1ml	0.9575	0.03	Barium Paste 1ml	0.5064	0.04
Barium Paste 3ml	0.9608	0.05	Barium Paste 3ml	0.5423	0.05
Barium Paste 5ml	1.0635	0.05	Barium Paste 5ml	0.5444	0.05
Barium Paste 10ml	0.9744	0.05	Barium Paste 10ml	0.5875	0.05
Barium Paste 20ml	1.2547	0.07	Barium Paste 20ml	0.7021	0.04

Table 4. ANOVA for average amplitude of EMG muscle activity

Effect	F Ratio	df	Error df	Significance
Muscle	89.016	1.000	9.000	0.000
Consistency	17.000	2.739	24.648	0.000
Volume	20.891	2.890	26.013	0.000
Muscle x Consistency	11.491	4.307	38.766	0.000
Consistency x Volume	1.225	15.004	135.035	0.260
Muscle x Volume	0.808	2.772	24.946	0.493
Muscle x Consistency x Volume	1.843	11.676	105.088	0.052

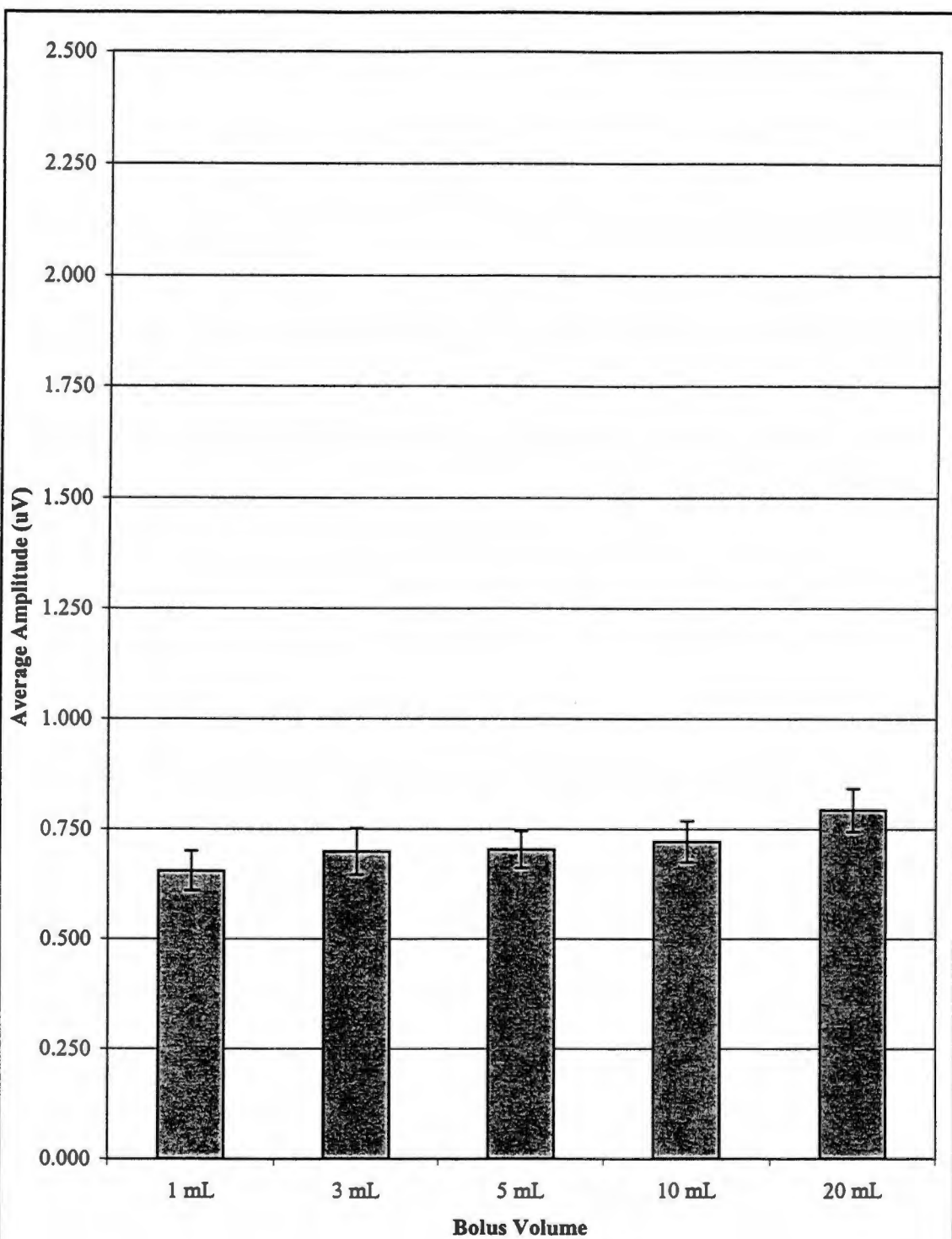
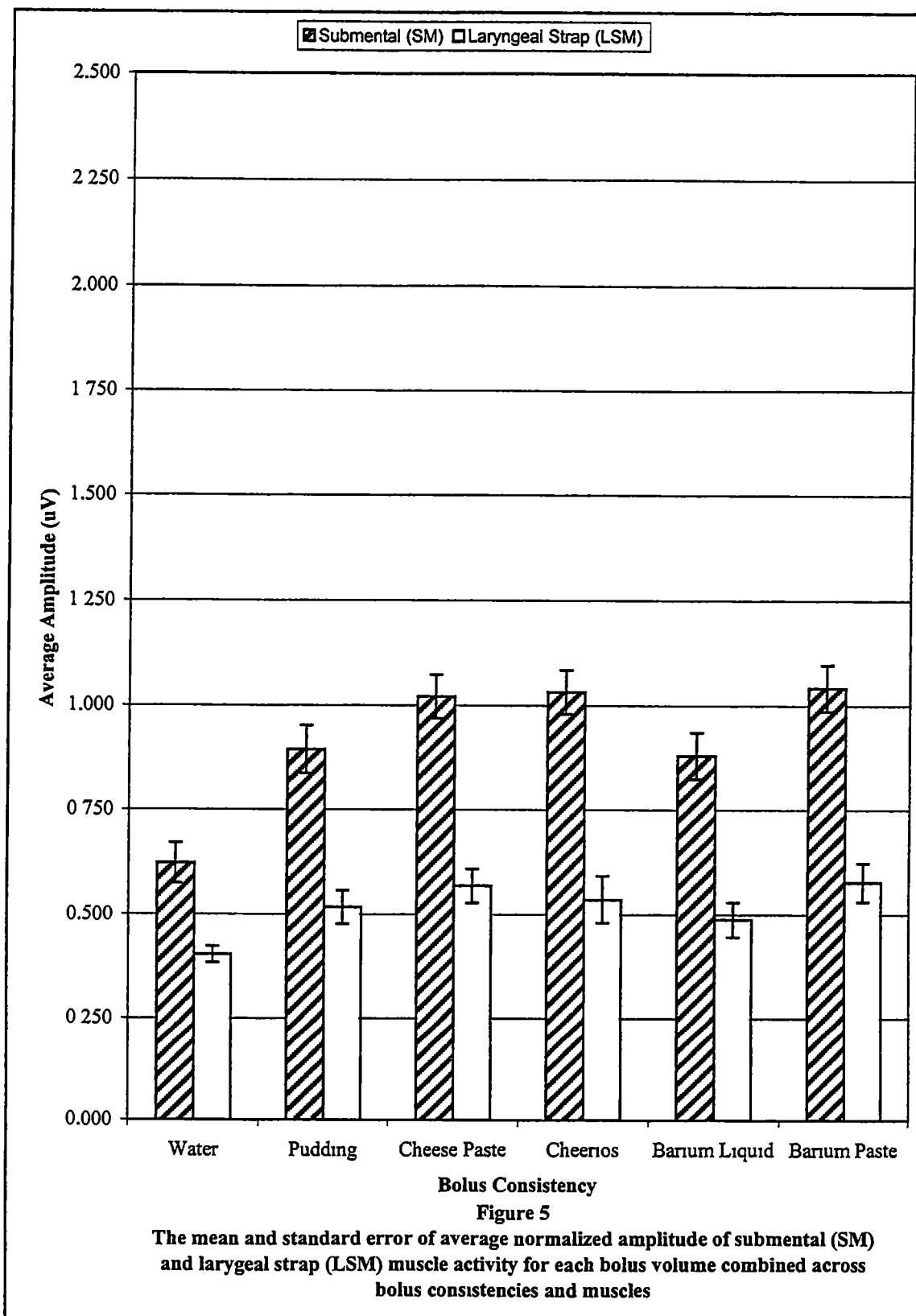


Figure 4
The mean and standard error of average normalized amplitude of muscle activity
for each bolus volume combined across bolus consistencies and muscles

of cheese paste compared to swallows of pudding, and swallows of barium paste compared to swallows of barium liquid.

Normalized amplitude of the LSM muscle increased significantly for swallows of pudding, cheese paste and barium paste when compared to swallows of water. Swallows of cheese paste and barium paste yielded a significant increase in normalized amplitude of LSM muscle activity compared to swallows of liquid barium. Figure 5 shows the results of the post-hoc analysis of the interaction between muscle and consistency for normalized amplitude of muscle activity.



CHAPTER IV

Discussion

Findings of this investigation indicate that bolus volume and consistency significantly affect the amplitude and duration of SM and LSM muscle activity during swallowing in adults. These findings may be of importance in the evaluation and treatment of individuals with dysphagia.

Average Duration

Consistency Effects

Results from previous studies indicate that bolus consistency significantly affects the duration of muscle activity during swallowing. Reimers-Neils et al. (1994) found an increase in the total swallow duration from liquids to thin pastes and from thin pastes to thick pastes. Ruark et al. (1999) determined that the average duration of both SM and LSM activity systematically increased across bolus consistencies. Specifically, Ruark and colleagues found that for SM activity, significant increases in average duration occurred for swallows of cheese paste compared to swallows of water. Significant increases in average duration of LSM activity occurred for swallows of pudding and cheese paste versus water, and cheese paste versus gummy bears (Ruark et al., 1999). Reimers-Neils et al. (1994) found that thin paste consistencies yielded longer duration of muscle activity than liquids.

Certain findings of the present study were similar to results found by Reimers-Niels et al. (1994) and by Ruark et al. (1999), while other findings were dissimilar. As in the previous research, the present investigation identified a consistency effect for average duration of muscle activity. Results of this study found that swallows of pudding, cheese paste, Cheerios®, and barium paste produced a significant increase in average duration of muscle activity compared to boluses of water regardless of volume or muscle. Although significant differences were found only with swallows of the thicker consistencies compared to swallows of water, the average duration of muscle activity increased systematically across bolus consistency (see Figure 3, p. 23).

Conversely, some of the results of the current study did not support findings of Reimers-Neils et al. (1994) and Ruark et al. (1999). Reimers-Neils and colleagues found that thick paste consistencies yielded longer duration of muscle activity than thin paste consistencies. However, results of the present study did not reveal a significant difference in duration for these consistencies (see Figure 3, p. 23). Additionally, findings of this investigation did not support specific findings of Ruark et al. (1999) for SM and LSM activity. The current investigation found that bolus consistency similarly affected the average duration of SM and LSM activity during swallowing. The differences in the current findings and those of Reimers-Neils et al. (1994) and Ruark et al. (1999) may be explained by the methodological variations between the studies (i.e., for the present study, multiple volumes and additional consistencies were presented).

In contrast to the findings of Dantas and Dodds (1990), the current investigation did not find significant differences in average duration of muscle activity for swallows of barium paste versus barium liquid. Again, methodological variation between these studies may account for the conflicting results. Methodological differences for the present investigation include the following: 1) the present investigation utilized a calculated standard deviation in the data selection process and, 2) additional volumes and food consistencies were presented in addition to barium liquid and paste.

Volume Effects

Of the existing research, only the study by Ertekin et al. (1997) found bolus volume to affect the duration of muscle activity during swallowing. Results from this study revealed that duration of muscle activity increased as bolus volume increased from 3 to 20 ml of water (Ertekin et al., 1997). Results of the present investigation also indicated that the average duration of muscle activity increased as a result of bolus volume. However, significant differences occurred only when participants swallowed boluses of 20 ml as compared to boluses of 1 ml.

Average Amplitude

Consistency Effects

Ruark et al. (1999) found bolus consistency to have similar effects on SM and LSM muscle activity. Conversely, results of the investigation by Reimers-Neils et al. (1994) indicated that the effects of bolus consistency on amplitude of muscle activity during swallowing are dependent upon the muscle involved. Results of the present

investigation support this finding. Reimers-Neils et al. (1994) found that the average amplitude of SM activity increased significantly for swallows of thick paste compared to swallows of liquid and thin paste. The present investigation found that the normalized amplitude of muscle activity increased significantly for swallows of pudding, cheese paste, Cheerios®, barium liquid and barium paste when compared to swallows of water. Significant increases in the normalized amplitude of SM activity also occurred for swallows of cheese paste compared to swallows of pudding, and for swallows of barium paste compared to swallows of barium liquid. Reimers-Neils and colleagues (1994) and the present investigation found SM activity to be more sensitive to changes in bolus consistency than LSM activity, as the normalized amplitude of SM activity was significantly affected by a greater number of consistencies.

Reimers-Neils et al. (1994) found that the average amplitude of IH muscle activity increased significantly for swallows of thick paste compared to swallows of liquid. However, no results were observed for thin versus thick pastes (Reimers-Neils et al., 1994). The present investigation also found significant increases in the normalized amplitude of LSM activity for swallows of pudding, cheese paste and barium paste compared to swallows of water. Swallows of cheese paste and barium paste also produced significant increases in normalized amplitude of LSM activity when compared to swallows of barium liquid.

Dantas and Dodds (1990) reported that the average amplitude of SM and IH muscle activity increased significantly for barium paste as compared to barium liquid. Results of the current investigation are consistent with this finding.

Volume Effects

Effects of bolus volume on average amplitude of muscle activity were not observed in studies conducted by Dantas and Dodds (1990), Dantas et al. (1989), or Ertekin et al. (1997). The current investigation, however, found that normalized amplitude of muscle activity increased significantly for swallows of 20 ml compared to swallows of 1, 3, and 5 ml regardless of muscle or consistency. In comparison to Dantas and colleagues (1989; 1990), the present investigation included food substances (i.e. water, pudding, cheese paste, and Cheerios®) in addition to barium consistencies (liquid and paste). In the investigation by Ertekin et al. (1997), food substances were limited to water and pudding, and EMG activity for the laryngeal strap muscle was not recorded. These methodological differences may explain why these investigations did not find effects of bolus volume on the amplitude of muscle activity.

Clinical Significance

The results of this investigation indicate that bolus volume and consistency significantly affect the amplitude and duration of muscle activity during swallowing. Bolus volume and consistency are important considerations when performing swallowing evaluations, as in a modified barium swallow study, or during treatment of swallowing disorders. During a modified barium swallow study (MBS), various volumes and

consistencies of food and barium textures are presented. Currently, no standardized measures of volume or consistency are used when performing this type of evaluation. Results of this study indicate that muscle activity during swallowing is not consistent across bolus volume and consistency. Therefore, according to these results, standardized measures for bolus volume and consistency should be adopted for use during swallowing evaluations and in treatment of swallowing disorders.

Limitations of the Current Study

The current study examined the effects of bolus volume and consistency on the amplitude and duration of muscle activity during swallowing in 10 young adult females. Limitations of the current study include the limited sample size and the narrow age range. In addition, the lack of videofluoroscopy to accompany the EMG data increased the difficulty of identifying the swallow.

Suggestion for Future Research

Results of this investigation both support and dispute findings of previous investigations. Thus, further research is suggested. In order to examine the effects of bolus volume and consistency on the muscle activity in other age groups, this study is part of a larger investigation including 10 typically developing five-year-old female children. Additionally, the current study could be extended by comparing each consistency of barium liquid included in modified barium studies, as well as the thickened liquids that they represent. Finally, the use of videofluoroscopy in conjunction with EMG would enable more definitive identification of the swallow and allow further

conclusions as to the effects of bolus volume and consistency on muscle activity during swallowing.

Summary

In conclusion, results of this investigation indicate that bolus volume and consistency significantly affect the amplitude and duration of SM and LSM muscle activity during swallowing in adults. In regard to average duration of muscle activity, significant main effects were observed for both volume and consistency. For normalized amplitude of muscle activity, results of the analyses revealed a significant main effect for volume, in addition to a significant interaction between muscle and consistency. These findings suggest that bolus volume and consistency influence swallowing coordination and should be considered in the evaluation and treatment of individuals with dysphagia.

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APPENDICES

APPENDIX A

PARTICIPANT INFORMATION SHEET

PARTICIPANT INFORMATION SHEET

Researcher's name. _____

Date: _____

A. Background History:

Name: _____

Date of Birth. _____ Age _____

Address: _____

Phone. (work) _____ (home) _____

B. Related Medical History

Check the following if the answer is YES, place comments next to sentence

_____ I am currently free of upper respiratory infection

_____ My hearing is normal

_____ I have no middle ear problems at this time

_____ I have no neurological difficulties (ie. history of seizures, brain trauma, etc.)

_____ I have no current illness/medication that may affect speech/language/swallowing
(Please list all current medications)

_____ My general health is OK

_____ I have no history of speech and/or language delay and no history of receiving
remedial services from the school systems

_____ I have no history of delay in developmental milestones

_____ I have no gross motor difficulties

_____ I speak English as my primary language

_____ I am not allergic to any of the foods being presented in this study

APPENDIX B

CRANIAL NERVE SCREENING FORM

Cranial Nerve Screening

1. Trigeminal Nerve (V)

- Sensory Function

_____ When a Q-tip is lightly brushed over maxilla and mandible, participant raises hand in response

_____ When the teeth and anterior two-thirds of tongue are lightly touched with a tongue depressor, participant raises hand in response.

- Motor Function

_____ No deviation or weakness is noted during jaw opening and closing.

_____ When teeth are clenched, masseter and temporalis muscle contraction can be felt by palpation.

2. Facial Nerve (VII)

- Motor Function

_____ Smiling reveals equal areas of the upper and lower teeth on both sides.

_____ No difference is noted between automatic and voluntary facial responses.

3. Glossopharyngeal (IX)

- Posterior one-third of tongue

_____ Participant detects light pressure to the back of the tongue.

4. Vagus Nerve (X)

- Soft Palate

_____ When participant says "ahhh", the soft palate elevates and the uvula moves posteriorly.

5. Hypoglossal (XII)

- Motor Function

_____ When tongue is protruded at midline, there is no apparent deviation or atrophy.

_____ Participant is able to move tongue from side to side and up and down .

APPENDIX C

ORAL SPEECH MECHANISM SCREENING EXAMINATION – REVISED

Oral Speech Mechanism Screening Examination - Revised

The Oral Speech Mechanism Screening Examination - Revised (OSMSE-R) was developed to screen the anatomy and physiology of the oral speech mechanism. The structures tested include the lips, tongue, jaw, hard and soft palate, pharynx, respiration, velopharyngeal mechanism, and diadochokinetic rate. This test was formally standardized on 211 subjects. Normative data is provided for individuals ages 5:3 to 77:7, however the test may be used with individuals outside of this age range.

APPENDIX D
PARTICIPANT CONSENT FORM



College of Arts & Sciences
Department of Audiology & Speech Pathology
457 South Stadium Hall
Knoxville, Tennessee 37996-0740
(423) 974-5019
FAX (423) 974-1539

Consent to Participate in a Research Study

Title: Oral-facial muscle activity in children and adults

Investigator: Jack L. Ruark, Ph.D.
444 South Stadium Hall
University of Tennessee, Knoxville
Knoxville, Tennessee 37996

Description

There is little known about the development of speech movements and their relationship to other oral movements, such as chewing. An understanding of the relationship between speech and nonspeech oral movements (e.g., chewing, swallowing) is needed, so that we can understand how speech develops, and how we can help those children with developmental motor speech disorders.

You will participate in a study to help us understand how orofacial muscles are used for speech and nonspeech activities. The procedure we use to measure orofacial activity is simple and causes no discomfort. We will simply measure the activity in your orofacial muscles as you eat a snack.

As you sit in a chair, small surface electrodes (i.e., sensors) will be placed on your face and on your neck. You will then eat a snack. During this time, orofacial muscle activity will be recorded onto a multichannel tape recorder. The experiment will take approximately 45 minutes, however, you may stop at any time if you wish to discontinue the study.

In addition to the snack, we would like to include an optional task for you to perform. This task includes swallowing a small amount of banum powder mixed with water and flavored syrup, and a small amount of banum paste mixed with syrup. Banum is a safe substance, and is used daily in studies at clinics and hospitals. The total amount of banum will be 5.5 oz. This task is completely optional, and if you choose not to participate in this task, you will still be included in the remainder of the study.

Before participating in the study, you will answer some questions pertaining to your health history, and you will receive a swallowing and oral mechanism screening by a certified speech language pathologist.

Risk and Benefits

There are no known risks associated with the procedures in this study. This electrode procedure causes no discomfort to you, and the items we ask you to swallow are safe. We have used this procedure on infants, small children, and adults with no difficulties. All equipment is sterilized before each session.

You will not benefit directly from participating in this study. However, this information will help us understand how orofacial muscles are used for speech and nonspeech activities, and how the coordination of orofacial muscles changes over time.

understand how orofacial muscles are used for speech and nonspeech activities, and how the coordination of orofacial muscles changes over time.

Cost and Payments

There will be no charge to you. At your request, you may withdraw from the study at anytime

Confidentiality

Any information obtained from you for this research project will be kept confidential. The data being obtained will be for the sole use of the named investigator

Right to Refuse or End Participation

You are free to refuse participation in this research project or to withdraw at any time without penalty

Voluntary Consent

I certify that I have read the preceding or it has been explained to me and that I understand its content. Any questions that I have regarding this research project have been answered by the investigator. A copy of this consent form will be given to me. My signature below means that I have freely agreed to participate in this research study.

Name of subject: _____

Subject's signature _____ Date _____

Investigator's signature _____ Date _____

Witness _____

I also verify that I have read the list of foods that are used in this study and that to my knowledge, I do not have any known allergies of these foods

Subject's signature _____

APPENDIX E
EXPERIMENTAL TASK INSTRUCTIONS

Experimental Task Instructions

For each trial, the participant was instructed to swallow when the computer screen was clear of EMG activity or movement artifact

Water: "Put this in your mouth. Hold it there but don't swallow yet" "OK, swallow".

Pudding: "Put this in your mouth. Chew it up and get it ready to swallow, but don't swallow yet. Raise your hand when you are ready to swallow". "OK, swallow".

Cheese Paste: "Put this in your mouth. Chew it up and get it ready to swallow, but don't swallow yet. Raise your hand when you are ready to swallow". "OK, swallow".

Cheerios: "Put this in your mouth. Chew it up and get it ready to swallow, but don't swallow yet. Raise your hand when you are ready to swallow". "OK, swallow".

Barium Liquid: "I'm going to put this in your mouth. Hold it there but don't swallow yet." "OK, swallow".

Barium Paste: "Put this in your mouth. Chew it up and get it ready to swallow, but don't swallow yet. Raise your hand when you are ready to swallow". "OK, swallow".

APPENDIX F
INDIVIDUAL MEANS FOR DURATION OF SM AND LSM ACTIVITY

Individual means for duration of submental and laryngeal strap muscle activity
(in seconds)

Set A SM

Participant	Water 1ml	Water 3ml	Water 5ml	Water 10ml	Water 20ml	Pudding 1ml	Pudding 3ml	Pudding 5ml	Pudding 10ml	Pudding 20ml	Cheese 1ml	Cheese 3ml	Cheese 5ml	Cheese 10ml	Cheese 20ml
1	0.755	0.635	0.604	0.687	1.047	1.036	0.975	1.168	1.191	1.603	1.092	1.001	1.149	1.493	1.490
2	0.907	0.861	0.986	1.028	1.020	1.237	1.103	0.869	0.808	1.217	0.899	0.767	0.979	0.983	1.194
3	1.002	0.937	1.172	1.239	1.195	1.184	1.289	1.194	1.271	1.180	1.017	1.190	1.073	1.107	1.032
4	1.088	1.115	1.278	1.119	0.915	1.141	1.467	1.399	1.690	1.066	1.300	1.645	1.323	1.191	1.512
5	0.839	0.839	0.850	0.801	0.733	1.354	0.990	0.968	1.167	1.221	1.478	1.054	1.228	1.441	1.236
6	0.907	1.039	1.384	1.395	1.191	1.255	1.422	1.301	1.376	1.470	1.645	1.443	1.398	1.538	1.485
7	0.975	0.919	0.876	1.020	1.073	1.240	1.369	1.429	1.357	1.282	1.027	1.153	1.145	1.244	1.217
8	1.157	1.137	1.190	1.138	1.362	1.244	1.195	1.020	1.630	1.221	1.304	1.130	1.407	1.414	1.403
9	1.325	1.293	1.322	1.082	1.131	1.089	1.354	1.459	1.387	1.433	1.584	1.418	1.387	1.452	1.528
10	0.937	0.990	0.994	0.846	0.933	1.448	1.376	1.475	1.080	1.160	1.134	1.354	1.183	1.047	1.187

Set B LSM

Participant	Water 1ml	Water 3ml	Water 5ml	Water 10ml	Water 20ml	Pudding 1ml	Pudding 3ml	Pudding 5ml	Pudding 10ml	Pudding 20ml	Cheese 1ml	Cheese 3ml	Cheese 5ml	Cheese 10ml	Cheese 20ml
1	0.688	0.657	0.695	0.752	1.062	1.111	1.036	1.251	1.172	1.516	1.107	0.982	1.172	1.542	1.475
2	0.918	0.945	1.039	1.050	1.016	1.301	1.175	0.937	0.880	1.232	1.001	0.820	1.051	1.122	1.225
3	0.994	0.982	1.168	1.164	1.214	1.145	1.293	1.217	1.251	1.240	1.217	0.945	1.047	1.119	0.945
4	1.153	1.024	1.365	1.175	0.933	1.119	1.429	1.565	1.706	1.050	1.346	1.618	1.402	1.255	1.550
5	1.016	0.899	0.990	0.941	0.971	1.414	0.998	0.952	1.119	1.236	1.543	1.074	1.270	1.187	1.281
6	0.960	1.073	1.285	1.179	0.759	1.138	1.210	1.232	1.285	1.259	1.679	1.438	1.342	1.558	1.520
7	1.062	0.907	1.031	1.138	1.103	1.290	1.384	1.387	1.441	1.350	1.096	1.239	1.137	1.255	1.145
8	1.391	1.282	1.338	1.210	1.316	1.388	1.308	1.115	1.652	1.286	1.255	1.225	1.463	1.528	1.429
9	1.334	1.191	1.473	1.091	1.024	1.056	1.308	1.486	1.361	1.331	1.528	1.490	1.418	1.444	1.373
10	1.032	1.039	1.039	0.888	0.933	1.437	1.399	1.717	1.171	1.167	1.217	1.342	1.221	1.201	1.229

Participant	1 Cheeno	3 Cheenos	5 Cheenos	10 Cheenos	20 Cheenos	B Liq 1ml	B Liq 3ml	B Liq 10ml	B Liq 20ml	B Paste 1ml	B Paste 3ml	B Paste 5ml	B Paste10ml	B Paste20ml
1	0933	1024	1368	1262	1020	1050	1142	1320	1058	1043	1122	1701	1054	0997
2	1088	1088	0956	0994	1032	0930	0877	0820	0854	0895	0816	0770	1070	1251
3	1433	1304	1183	1240	1376	0963	1122	1292	1615	1221	1403	1539	1599	1486
4	1547	1493	1300	1285	1338	1463	1312	1482	1422	1244	1384	1569	1494	1485
5	1440	1342	1509	1346	1637	0960	1263	1066	1429	1629	1566	1527	1758	1739
6	1253	1328	1621	1607	1553	1080	1327	1217	1387	1426	1478	1561	1830	1721
7	1009	1194	1077	1077	1233	1058	1107	1460	1255	0831	1062	1142	1312	1607
8	1088	1244	1467	1323	1546	1361	1084	1020	1153	0986	1115	1111	1133	1220
9	1542	1293	1198	1244	1179	1107	1186	1297	1202	1255	1289	1346	1308	1440
10	1633	1448	1467	1301	1622	1130	1338	1353	1387	1297	1418	1456	1652	1898

Participant	1 Cheeno	3 Cheenos	5 Cheenos	10 Cheenos	20 Cheenos	B Liq 1ml	B Liq 3ml	B Liq 10ml	B Liq 20ml	B Paste 1ml	B Paste 3ml	B Paste 5ml	B Paste10ml	B Paste20ml
1	0906	1115	1418	1232	1036	1153	1145	1311	1051	1009	1168	1894	1054	1043
2	1103	1157	1103	1054	1001	1028	1031	0922	0963	1028	0888	0929	1099	1228
3	1524	1297	1274	1243	1399	1081	1240	1323	1501	1353	1418	1550	1546	1429
4	1539	1440	1258	1331	1342	1547	1444	1346	1399	1319	1331	1539	1493	1459
5	1160	1349	1474	1233	1614	0956	1255	1111	1312	1437	1599	1516	1656	1785
6	1248	1328	1561	1603	1549	1106	1312	1085	1418	1473	1440	1486	1740	1648
7	1130	1232	1100	1115	1270	1088	1210	1482	1297	0865	1134	1153	1266	1508
8	1040	1282	1490	1384	1577	1320	1122	1047	1100	1069	1138	1134	1077	1149
9	1482	1353	1175	1304	1225	1160	1293	1278	1210	1403	1271	1255	1247	1463
10	1675	1415	1512	1372	1652	1217	1323	1456	1361	1319	1548	1414	1675	1913

APPENDIX G
INDIVIDUAL AND NORMALIZED MEANS FOR AMPLITUDE OF SM AND LSM
ACTIVITY

Individual and normalized means for amplitude of submental and laryngeal strap muscle activity (m uV)

Set A SM

Participant	Water 1ml	Water 3ml	Water 5ml	Water 10ml	Water 20ml	Pudding 1ml	Pudding 3ml	Pudding 5ml	Pudding 10ml	Pudding 20ml	Cheese 1ml	Cheese 3ml	Cheese 5ml
1	7.382	7.259	8.308	8.852	13.747	15.090	10.528	14.214	13.003	17.313	15.796	17.365	16.219
n	0.350	0.344	0.404	0.420	0.652	0.716	0.500	0.674	0.617	0.821	0.749	0.824	0.770
2	17.690	17.822	17.836	17.473	19.302	22.723	23.950	19.123	17.889	16.346	25.754	18.622	21.158
n	0.741	0.747	0.747	0.732	0.809	0.952	1.003	0.801	0.749	0.685	1.079	0.780	0.886
3	9.265	7.708	6.130	6.474	8.940	11.306	11.479	9.943	11.301	12.683	11.244	11.953	15.088
n	0.769	0.640	0.509	0.538	0.742	0.939	0.953	0.826	0.939	1.053	0.934	0.993	1.253
4	8.119	9.743	9.100	6.639	7.038	11.369	10.232	10.849	9.885	14.626	15.036	13.348	12.430
n	0.560	0.672	0.628	0.458	0.486	0.784	0.706	0.749	0.682	1.009	1.038	0.921	0.858
5	8.296	6.432	6.425	6.754	6.092	13.839	16.050	14.086	10.162	10.222	13.938	12.107	11.291
n	0.582	0.451	0.450	0.474	0.427	0.970	1.125	0.988	0.712	0.717	0.977	0.849	0.792
6	7.266	5.940	7.220	7.242	8.311	8.047	11.479	10.643	10.693	12.822	11.281	12.651	11.250
n	0.545	0.446	0.542	0.543	0.624	0.604	0.861	0.799	0.802	0.962	0.847	0.949	0.844
7	6.083	6.028	7.251	6.125	7.554	11.079	14.217	11.675	13.761	11.558	11.986	15.834	13.935
n	0.474	0.469	0.565	0.477	0.588	0.863	1.107	0.909	1.072	0.900	0.934	1.233	1.085
8	9.233	9.174	10.478	11.439	12.541	8.342	14.686	12.490	12.886	14.363	13.766	14.328	15.082
n	0.653	0.649	0.741	0.809	0.887	0.590	1.038	0.883	0.911	1.015	0.973	1.013	1.066
9	10.489	13.292	11.755	15.391	16.143	17.749	20.321	20.081	24.693	25.693	23.376	28.769	26.372
n	0.605	0.766	0.677	0.887	0.930	1.023	1.171	1.157	1.423	1.481	1.347	1.658	1.520
10	8.197	9.033	4.447	10.357	10.333	6.870	8.750	10.154	11.400	12.625	9.292	9.359	10.731
n	0.742	0.818	0.403	0.938	0.936	0.622	0.792	0.919	1.032	1.143	0.842	0.848	0.918

Set B LSM

Participant	Water 1ml	Water 3ml	Water 5ml	Water 10ml	Water 20ml	Pudding 1ml	Pudding 3ml	Pudding 5ml	Pudding 10ml	Pudding 20ml	Cheese 1ml	Cheese 3ml	Cheese 5ml
1	6.024	7.851	8.417	8.368	8.683	6.029	6.196	6.802	5.713	7.895	6.460	7.795	7.655
n	0.286	0.373	0.399	0.397	0.412	0.286	0.294	0.323	0.271	0.375	0.307	0.370	0.363
2	6.268	6.967	7.260	7.918	8.299	8.424	8.682	12.991	8.687	9.647	7.944	7.134	8.385
n	0.263	0.292	0.304	0.332	0.348	0.353	0.364	0.344	0.364	0.404	0.299	0.299	0.351
3	6.618	5.569	5.426	5.294	6.810	8.605	7.566	6.646	7.674	8.454	7.260	6.965	8.075
n	0.590	0.463	0.451	0.440	0.566	0.715	0.628	0.552	0.637	0.702	0.603	0.578	0.671
4	4.769	5.047	5.353	4.878	5.490	6.087	5.785	5.717	5.890	7.231	7.710	6.841	7.811
n	0.329	0.348	0.369	0.337	0.379	0.420	0.399	0.395	0.406	0.499	0.532	0.472	0.539
5	5.762	5.759	5.973	5.998	7.983	8.020	10.433	10.232	8.713	8.348	8.132	8.626	8.519
n	0.404	0.404	0.419	0.421	0.560	0.562	0.731	0.717	0.611	0.585	0.570	0.605	0.597
6	3.719	3.500	4.363	4.166	5.450	3.771	5.631	5.820	5.407	7.587	5.907	6.693	6.411
n	0.279	0.263	0.327	0.313	0.396	0.283	0.423	0.437	0.406	0.569	0.443	0.502	0.481
7	3.715	4.667	5.029	4.395	5.083	6.193	8.844	8.036	9.451	9.891	8.137	11.250	9.727
n	0.289	0.363	0.392	0.342	0.396	0.482	0.689	0.670	0.736	0.770	0.634	0.876	0.758
8	4.847	5.236	5.598	6.199	7.009	4.700	7.304	6.570	7.109	7.135	7.173	7.463	8.049
n	0.343	0.370	0.396	0.438	0.495	0.332	0.516	0.464	0.503	0.504	0.507	0.528	0.569
9	5.775	9.634	6.693	8.014	9.429	8.351	9.206	8.971	11.773	11.641	9.633	12.286	10.055
n	0.333	0.555	0.386	0.462	0.543	0.481	0.571	0.517	0.678	0.671	0.555	0.708	0.579
10	5.626	6.011	3.576	6.493	6.095	6.647	6.173	6.015	7.303	7.994	6.401	6.515	6.854
n	0.509	0.544	0.324	0.588	0.552	0.602	0.559	0.545	0.661	0.741	0.580	0.590	0.621

n=normalized, b=barium, liq=liquid

Participant	Cheese 10ml	Cheese 20ml	1 Cheero	3 Cheeros	5 Cheeros	10 Cheeros	20 Cheeros	B Lq 1ml	B Lq 3ml	B Lq 10ml	B Lq 20ml	B Paste 1ml
1	21 507	20 168	13 656	14 778	13 972	13 326	11 159	16 849	17 217	16 828	26 437	18 437
n	1 020	0 957	0 648	0 701	0 663	0 632	0 529	0 799	0 817	0 798	1 254	0 875
2	33 107	25 928	24 185	35 656	39 047	24 013	31 670	18 832	17 313	21 720	20 437	24 843
n	1 387	1 086	1 013	1 494	1 636	1 006	1 327	0 789	0 725	0 910	0 856	1 041
3	15 619	11 666	11 575	13 528	16 019	14 580	14 122	9 122	13 350	8 876	10 582	12 345
n	1 297	0 969	0 961	1 123	1 330	1 211	1 173	0 758	1 109	0 737	0 879	1 025
4	15 827	17 359	11 816	13 000	12 400	14 238	12 573	8 241	9 082	7 067	10 192	12 206
n	1 092	0 974	0 815	0 897	0 856	0 982	0 868	0 569	0 627	0 488	0 703	0 842
5	13 745	15 316	15 102	16 232	16 059	18 155	20 137	12 128	12 777	11 919	13 400	15 855
n	0 964	1 074	1 059	1 138	1 126	1 273	1 412	0 850	0 896	0 836	0 939	1 112
6	10 734	13 571	9 887	9 264	9 095	8 369	10 516	9 993	10 227	9 635	11 140	10 812
n	0 806	1 018	0 742	0 695	0 683	0 628	0 789	0 750	0 767	0 723	0 764	0 811
7	13 056	12 734	9 724	8 616	8 218	8 462	13 166	9 465	10 901	12 056	16 508	9 914
n	1 017	0 992	0 757	0 671	0 640	0 659	1 025	0 737	0 849	0 939	1 286	0 772
8	15 634	15 074	10 939	14 486	15 186	14 996	14 752	11 252	12 975	13 880	12 660	14 924
n	1 105	1 066	0 773	1 024	1 074	1 060	1 043	0 795	0 917	0 981	0 895	1 055
9	23 621	17 465	27 804	26 276	30 701	29 844	27 613	12 676	20 194	18 098	19 839	17 100
n	1 361	1 007	1 602	1 514	1 769	1 720	1 591	0 731	1 164	1 248	1 143	0 986
10	11 777	11 165	11 131	12 220	11 786	13 547	11 722	12 636	10 864	14 583	10 493	11 664
n	1 066	1 011	1 008	1 107	1 067	1 227	1 062	1 144	0 984	1 321	0 950	1 056

Participant	Cheese 10ml	Cheese 20ml	1 Cheero	3 Cheeros	5 Cheeros	10 Cheeros	20 Cheeros	B Lq 1ml	B Lq 3ml	B Lq 10ml	B Lq 20ml	B Paste 1ml
1	8 405	9 122	4 955	6 654	7 063	7 197	6 511	8 655	7 950	7 953	11 323	9 246
n	0 399	0 433	0 235	0 316	0 335	0 341	0 309	0 411	0 377	0 377	0 537	0 439
2	11 301	12 025	6 795	7 482	7 015	5 757	7 938	5 243	5 839	5 821	8 583	6 001
n	0 473	0 504	0 285	0 313	0 294	0 241	0 333	0 220	0 245	0 244	0 360	0 251
3	10 257	9 752	6 834	5 990	8 231	8 255	8 795	5 044	7 442	5 886	7 491	7 685
n	0 852	0 810	0 568	0 497	0 684	0 686	0 730	0 419	0 618	0 489	0 622	0 638
4	8 405	10 397	6 471	6 719	7 377	6 948	7 119	5 317	5 637	5 080	6 500	6 008
n	0 580	0 611	0 447	0 464	0 509	0 479	0 491	0 367	0 389	0 351	0 488	0 415
5	9 937	11 971	8 660	9 320	9 331	11 420	11 875	8 883	8 107	7 872	8 913	9 244
n	0 697	0 839	0 607	0 653	0 654	0 801	0 833	0 623	0 568	0 552	0 625	0 648
6	5 810	6 013	5 363	5 174	5 224	4 813	5 793	4 917	4 694	4 242	4 973	5 361
n	0 316	0 451	0 402	0 388	0 392	0 361	0 435	0 369	0 352	0 318	0 373	0 402
7	8 818	10 214	6 729	6 046	6 055	6 565	8 003	10 306	7 884	8 194	9 787	7 555
n	0 687	0 796	0 524	0 471	0 472	0 511	0 623	0 803	0 614	0 638	0 762	0 588
8	8 333	8 499	6 127	7 542	7 079	7 003	7 161	5 681	6 299	7 371	7 119	7 815
n	0 589	0 601	0 433	0 533	0 500	0 495	0 506	0 402	0 445	0 521	0 503	0 552
9	9 759	12 031	13 213	14 095	15 281	16 412	16 512	6 572	8 962	8 625	10 433	7 183
n	0 562	0 693	0 761	0 812	0 881	0 946	0 952	0 379	0 517	0 497	0 601	0 414
10	7 478	8 079	7 319	7 377	6 717	7 681	7 221	7 584	6 772	7 270	7 624	7 902
n	0 677	0 732	0 663	0 668	0 608	0 696	0 654	0 687	0 613	0 658	0 690	0 716

Participant	B Paste 3ml	B Paste 5ml	B Paste10ml	B Paste20ml
1	17 486	22 286	21 400	32 711
n	0 830	1 057	1 015	1 552
2	23 515	23 808	25 107	26 707
n	1 069	0 997	1 052	1 119
3	12 678	14 178	12 247	14 167
n	1 053	1 178	1 017	1 177
4	11 330	10 685	9 037	22 747
n	0 782	0 737	0 624	1 570
5	15 988	14 648	11 026	12 489
n	1 121	1 027	0 773	0 876
6	9 465	11 809	11 462	14 011
n	0 710	0 886	0 860	1 051
7	10 053	13 419	13 171	16 565
n	0 783	1 045	1 026	1 290
8	14 652	14 481	14 065	14 880
n	1 036	1 024	0 994	1 052
9	19 795	24 162	22 839	23 972
n	1 141	1 392	1 316	1 382
10	11 973	14 260	11 774	16 334
n	1 084	1 291	1 066	1 479

Participant	B Paste 3ml	B Paste 5ml	B Paste10ml	B Paste20ml
1	7 948	7 750	8 671	15 273
n	0 377	0 368	0 411	0 725
2	5 956	6 140	10 439	11 071
n	0 250	0 257	0 437	0 464
3	8 982	8 590	8 545	8 795
n	0 746	0 713	0 710	0 730
4	6 203	6 013	6 295	12 087
n	0 428	0 415	0 434	0 834
5	10 452	10 105	9 865	11 525
n	0 733	0 708	0 692	0 808
6	5 179	5 294	5 530	6 699
n	0 389	0 397	0 415	0 503
7	8 882	9 675	11 824	11 932
n	0 692	0 753	0 921	0 929
8	7 336	7 617	7 790	8 716
n	0 519	0 538	0 551	0 616
9	9 716	11 747	11 499	11 296
n	0 560	0 677	0 663	0 651
10	8 072	6 802	7 086	8 404
n	0 731	0 616	0 642	0 761

VITA

Joy Allison Will was born in Norman, Oklahoma on December 12, 1974. She graduated Cum Laude from the University of Kentucky in May of 1998 with a Bachelor of Health Science in Communication Disorders. Ms. Will spent the spring semester of her junior year studying in Denmark at the University of Copenhagen.

Ms. Will is currently completing her Master of Arts degree in speech-language pathology at the University of Tennessee, Knoxville. She was a research assistant for two years in the motor speech laboratory under the supervision of Dr. Jack Ruark. During this time, she assisted in conducting studies of feeding development in infants with Down syndrome in addition to basic science research investigating swallowing development in typically developing children. In the summer of 1999, Ms. Will was awarded a summer graduate research assistanceship by the UTK Office of Research. She received clinical experience at the University of Tennessee Medical Center, the Pediatric Language Center, the University of Tennessee Hearing and Speech Center and in the Blount Co. school system.

Upon graduation from the University of Tennessee, Ms. Will plans to pursue a career in speech-language pathology in an acute care or rehabilitation facility. She will be married on June 17, 2000 to Mr. Robert Naylor.