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Viscosity Effects on EMG Activity in Normal Swallow

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Abstract. This study investigated the effects of six consistencies on measures of swallow duration, muscle activity, and sound. Electromyographic (EMG) recordings of the submental and infrahyoid muscle complexes, and audio recordings of neck sounds were made while 5 normal subjects swallowed two foods in each of three consistency categories: liquid, thin paste, and thick paste. Total swallow duration, measured from EMG, increased significantly across consistency categories from liquids to thin pastes to thick pastes. Liquids and thin pastes were significantly different from thick pastes on all but one EMG measure. However, liquids and thin pastes failed to reach significance on any of the EMG measures. EMG activity in the submental muscles most often initiated the swallow whereas the infrahyoid muscle activity most frequently terminated the swallow. A sound spike occurred at relatively the same time in each swallow. Results are discussed in terms of systematic modulations of muscle activity during swallow.

Key words: Bolus viscosity — Electromyography — Acoustic recordings — Deglutition — Deglutition disorders.

A variety of bolus consistencies are frequently presented during the evaluation and treatment of swallowing disorders. During the modified barium swallow, presentation of liquid, paste, and masticated materials (cookie) are recommended [1].

Studies of the influence of bolus consistency on normal swallow dynamics have reported changes in the durations and amplitudes of several oral and pharyngeal swallow events as the result of different bolus consistencies. Most of these previous investigations have utilized radiographic imaging, manometry, and/or endoscopy [2–7]. Only one study incorporated surface electromyography (EMG) [8]. However, the purpose of the study was to examine the temporal relation of the EMG data to other swallow events; the amplitude of the EMG data was not reported. Sound signals from the neck during swallow have also been analyzed and used previously to identify the swallow event [9–16].

Surface EMG and sound recordings have the advantage over radiographic, manometric, and endoscopic procedures for the study of swallow, as they are noninvasive. However, very little information exists on the changes in muscle activity and sound that may be present during swallows of various bolus consistencies in normal subjects.

The present investigation examined the effects of swallowing six bolus consistencies on EMG activity in two muscle groups: submandibular and infrahyoid muscles, and on the sounds of swallow.

Materials and Methods

Five normal volunteers (4 women and 1 man), between the ages of 25 and 42, participated in this protocol. The subjects reported no history of dysphagia and no medical problems or medications that might affect swallowing. The protocol was approved by the Northwestern University Institutional Review Board, and all subjects signed consent forms.

Five Sensor-Medics skin electrodes were utilized for each subject. The subject's skin was scrubbed; one pair of electrodes was taped to the skin under the chin on both sides of the midline and a second pair of electrodes was placed above the right superior border of the thyroid cartilage. A single electrode was affixed to the right earlobe as ground.

The electrodes placed under the subject's chin recorded the EMG activity from the submental muscle group: anterior belly of the digastric, mylohyoid, and geniohyoid. Those electrodes placed above the thyroid cartilage recorded activity from the infrahyoid (predominantly the thyrohyoid) muscles. In addition, a Knowles Electronics vibration transducer, BU-1771, was taped to the skin at, but not contacting, the inferior-lateral border of the thyroid cartilage.

Each subject was given a button connected to a KYFHO Laboratories interval actuator and instructed to depress the button when they

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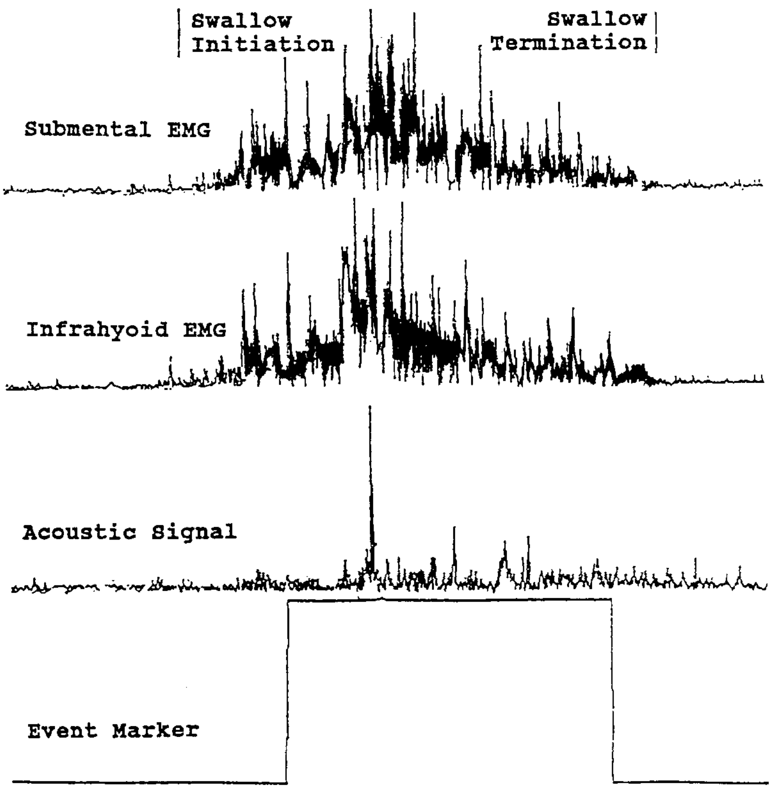

Fig. 1. Graphic display of the four data channels.

initiated each swallow and to release the button when each swallow was terminated. The 5 volt DC signal generated when the button was pressed served as the swallow event marker.

The signals from the two pair of EMG electrodes and the vibration transducer were differentially amplified by Grass AC preamplifiers, model P511, and filtered using a bandwidth of 100–3000 Hz. The output from each amplifier was rectified and along with the event marker pulse, fed to a Phillips four channel, 35 MHz oscilloscope, Model PM 3305, for visual monitoring of the signals and into a Digital Corporation PDP 1173 computer with a Kennedy magnetic tape drive, model 9100, for digital recording. The signals were sampled at a rate of 10 kHz and stored on magnetic tape.

During the experiment, subjects were seated comfortably and instructed as follows:

> I am going to place a small amount of food in your mouth. I want you to hold it in your mouth until I tell you to swallow. As soon as you begin to swallow, press the button in your hand and hold it down until you are finished. Swallow the food in a single swallow as you normally would, but try to avoid head or facial movements.

Three food categories were used: liquid, thin paste, and thick paste. Within each category, two levels of consistency (one thinner and one thicker) were selected to represent gradual increases of consistency across the three food categories. Three swallows of 3-cc boluses of each of the following foods were used: fruit juice (Kraft-General Foods, White Plains, NY), tomato juice (Libby's Nestle Food Corporation, Purchase, NY), apple sauce (The Jewel Companies, Melrose Park, IL), chocolate pudding (Beatrice/Hunt-Wesson Incorporated, Fullerton, CA), cheese spread (Nabisco, East Hanover, NJ), and creamy peanut butter (Best Foods, CPC International Incorporated, Englewood Cliffs, NJ) for a total of 18 swallows per subject. Volume was held constant across all consistencies to ensure that differences in measures could be attributed to bolus consistency and not volume. One practice swallow was completed before recording each consistency to introduce the subject to the changing bolus flavor and consistency.

Each premeasured bolus was presented on a teaspoon. The digital computer was activated and the verbal signal to begin the swallow was given. The experimentor monitored the subject's use of the event marker; when the subject released the button, indicating the end of the swallow, data collection was terminated for the swallow.

A total of 18 swallows (three for each of the six foods) were recorded for each of the 5 subjects. Data from five swallows were not adequate for measurement, leaving a total of 85 swallows for data analysis.

The four data channels (submental EMG, infrahyoid EMG, vibration transducer, and interval actuator) for each swallow were displayed on the computer monitor, as shown in Figure 1. The signals were centered on the screen to allow for display of sufficient pre- and postswallow signal.

Initiation and termination of EMG activity for each swallow were marked and the interval was measured in seconds. Initiation was defined as the first elevation in EMG activity from baseline in either channel and termination as the point at which EMG activity returned to baseline in either channel. Total swallow duration, based on the initiation and termination of the swallow, was measured and is referred to as the designated window for each swallow. The EMG channel used to signify the initiation and termination of the swallow was documented for later analysis.

Maximum EMG voltage, and average EMG voltage per sec for both the submental and infrahyoid signals within the designated window were calculated. Maximum EMG activity was measured at the signal peak, and average EMG activity per sec was calculated from the sum of EMG activity within the designated window divided by the total swallow duration.

Table 1. Frequency (in %) of each EMG channel initiating and terminating the swallow individually and simultaneously for 3 cc boluses of the six consistencies (n = 15)

	Fruit juice	Tomato juice	Apple sauce	Chocolate pudding	Cheese spread	Peanut butter	p (Fisher's Exact Test)
Initiating EMG channel							
Submental	71.43	80.00	100.00	85.71	86.67	83.32	0.50
Infrahyoid	21.43	20.00	00.00	14.29	13.33	16.68	
Submental & Infrahyoid	7.14	00.00	00.00	00.00	00.00	00.00	
Terminating EMG channel							
Submental	28.57	20.00	20.00	14.29	33.33	25.00	0.75
Infrahyoid	57.14	80.00	80.00	78.57	66.67	66.68	
Submental & Infrahyoid	14.29	00.00	00.00	7.14	00.00	8.33	

Table 2. Means and SDs of the total swallow duration (in sec) for 3 cc boluses of the six consistencies (n = 15) and for the pooled data for the three consistency categories (n = 30)

	Fruit juice	Tomato juice	Apple sauce	Chocolate pudding	Cheese spread	Peanut butter
Mean	1.517	1.163	1.981	1.777	3.037	3.035
SD	0.676	0.217	0.541	0.340	0.759	0.951

	Liquids	Thin pastes	Thick pastes	$F_{obs(2, 79)}$	Anova p^a
Pooled					
mean	1.334	1.883	3.036	61.94	<0.0001
SE	0.096	0.085	0.160		

[a]Significant post hoc comparisons: liquids to thin paste $p < 0.05$; liquids to thick pastes $p < 0.05$; thin pastes to thick pastes $p < 0.05$.

The interval between the beginning of the swallow and onset of the sound spike was marked and converted to sec. This value was divided by the total swallow duration, multiplied by 100, and represented the location of the sound spike as a percentage of the total swallow duration.

Thus, a total of six measures were made for each swallow: (1) total swallow duration, (2) frequency of each EMG channel initiating swallow, (3) frequency of each EMG channel terminating swallow, (4) maximum EMG activity in each channel, (5) average EMG activity per sec in each channel, and (6) location of sound spike. The mean and standard deviation were calculated for each measure for each food. The EMG channel used to signify the initiation and termination of the swallow was compared across the six consistencies using Fisher's Exact Test. A three factor—subject (subjects 1–5) by food consistency (levels 1 or 2) by food category (categories 1–3) ANOVA was used to analyze the duration, EMG, and sound data.

Results

Fisher's Exact Test revealed no significant differences among the six foods in the EMG channel initiating or terminating the swallow (Table 1). The frequency with which each EMG channel initiated and terminated the swallow revealed a predominant pattern for all food consistencies. Most frequently, submental muscle activity initiated the swallows (84.52%) and infrahyoid muscle activity terminated the swallows (71.51%).

The remainder of the EMG variables and data from the sounds of swallow were analyzed using the three-way ANOVA. No significant interaction was found for the thinner foods vs. the thicker foods within each category. Thus, the thinner foods in each of the three categories could be pooled and compared with the pooled data on the thicker foods in each category. This analysis of the consistency main effect showed no significant difference between the thinner and thicker foods. Therefore, in the last analysis, the thinner and thicker foods within each category were pooled to enable analysis of the effects of liquids, thin pastes, and thick pastes on the duration, EMG, and sound measures. Significant differences ($p < 0.05$) across categories as determined by the category main effect were followed by pairwise *t*-tests.

Total swallow duration increased significantly across the three consistency categories from liquids to thin pastes and from thin pastes to thick pastes (Table 2).

Examination of the profile of EMG activity revealed that both EMG channels exhibited similar patterns of muscle activity (Fig. 1). For liquid swallows there was

Table 3. Means and SDs of the maximum EMG activity (in mV) for the submental and infrahyoid muscle complexes for 3 cc boluses of the six consistencies (n = 15) and the means and SEs of the pooled data for the three consistency categories (n = 30)

	Submental							
	Fruit juice	Tomato juice	Apple sauce	Chocolate pudding	Cheese spread	Peanut butter		
Mean	0.142	0.135	0.139	0.145	0.173	0.169		
SD	0.067	0.069	0.060	0.061	0.064	0.064		
	Liquids		Thin pastes		Thick pastes		$F_{obs(2, 79)}$	Anova p[a]
Pooled mean	0.138		0.142		0.171		10.93	0.0001
SE	0.012		0.011		0.012			

	Infrahyoid							
	Fruit juice	Tomato juice	Apple sauce	Chocolate pudding	Cheese spread	Peanut butter		
Mean	0.156	0.148	0.146	0.153	0.200	0.201		
SD	0.082	0.074	0.069	0.073	0.109	0.117		
	Liquids		Thin pastes		Thick pastes		$F_{obs(2, 79)}$	Anova p[a]
Pooled mean	0.152		0.149		0.200		14.65	0.0001
SE	0.014		0.013		0.021			

[a]Significant post hoc comparisons: Liquids to thick pastes $p < 0.05$; thin pastes to thick pastes $p < 0.05$.

a gradual increase in EMG amplitude to a single peak, followed by a gradual return to baseline. On thin and thick paste swallows there were usually two to three peaks of activity.

Maximum EMG activity increased significantly from liquids to thick pastes and from thin pastes to thick pastes for both submental and infrahyoid channels (Table 3). Liquids vs. thin pastes were not significantly different for either EMG channel.

The average EMG activity per second for the submental channel was identical to the results of the maximum EMG data (Table 4). Liquids and thin pastes were not significantly different from one another, but both were significantly different from thick pastes. The results of the average EMG activity per sec for the infrahyoid channel were similar with one exception; thin pastes were not significantly different from thick pastes as had been seen in all the other EMG data.

Main effects for subjects reached significance for total swallow duration, and maximum and average EMG for both muscle groups. This indicated that subjects exhibited individual swallow patterns that differed significantly from one another.

Typically, a single sound spike was observed in the sound data, as shown in Figure 1. When more than one spike was present, the spike with the greatest amplitude was chosen for measurement. The relative location of the spike onset in the total duration of the swallow was not significantly different across consistencies (Table 5).

Discussion

This study examined the effects of various bolus consistencies on total swallow duration, maximum and average EMG activity of the submental and infrahyoid muscle groups, frequency with which each muscle group initiated and terminated the swallow, and relative location of the sound spike onset during swallow.

Two foods were arbitrarily selected by the investigators to represent each of three consistencies: liquid, thin paste, and thick paste. Although the foods were selected on the basis of perceived increases in consistency, the two foods within each category were not significantly different from each other on any of the measures. Furthermore, liquids vs. thin pastes were not significantly different on any of the EMG measures. These findings suggest that subjective judgments regarding differences in food consistencies are not a valid method for selecting food for inclusion in a dysphagia evaluation or treatment protocol. Several previous investigations [20,21] support these results.

This study revealed a number of significant effects of increasing bolus consistency on normal swal-

Table 4. Means and SDs of the average EMG activity per sec (in mV) for the submental and infrahyoid muscle complexes for 3 cc boluses of the six consistencies (n = 15) and the means and SEs of the pooled data for the three consistency categories (n = 30)

	Submental							
	Fruit juice	Tomato juice	Apple sauce	Chocolate pudding	Cheese spread	Peanut butter		
Mean	4.231	4.406	4.447	4.091	5.604	5.303		
SD	1.490	1.822	2.240	1.972	1.836	1.638		
	Liquids		Thin pastes		Thick pastes		$F_{obs(2, 79)}$	Anova p^a
Pooled mean	4.321		4.275		5.470		7.75	0.0009
SE	0.305		0.387		0.332			
	Infrahyoid							
	Fruit juice	Tomato juice	Apple sauce	Chocolate pudding	Cheese spread	Peanut butter		
Mean	4.505	5.009	4.841	4.888	5.418	5.696		
SD	2.274	2.146	2.140	2.077	2.238	2.135		
	Liquids		Thin pastes		Thick pastes		$F_{obs(2, 79)}$	Anova p^a
Pooled mean	4.766		4.864		5.542		3.54	0.0339
SE	0.406		0.385		0.415			

[a]Significant post hoc comparisons: Liquids to thick pastes $p = 0.05$ (submental and infrayoid); thin pastes to thick pastes $p = 0.05$ (submental only).

Table 5. Means and SD of the onset of the sound spike (in percent of total swallow duration) for 3 cc boluses of the six consistencies (n = 15) and the means and SE of the pooled data for the three consistency categories (n = 30)

	Fruit juice	Tomato juice	Apple sauce	Chocolate pudding	Cheese spread	Peanut butter		
Mean	56.631	57.841	71.306	69.473	61.630	62.734		
SD	19.940	19.202	19.110	15.810	26.157	30.736		
	Liquids		Thin paste		Thick pastes		$F_{obs(2, 75)}$	Anova p
Pooled mean	57.257		70.429		62.121		2.550	0.085
SE	3.569		3.214		5.335			

lows. Significantly longer swallow duration was observed from liquids to thin pastes to thick pastes. Previous studies using other evaluation modalities also observed prolongation of several swallow events [2,5]. Specifically, high bolus viscosity was reported to (1) delay oral and pharyngeal bolus transit, (2) decrease the velocity of lingual peristalsis, (3) increase duration of pharyngeal peristaltic waves, and (4) prolong upper esophageal sphincter opening.

In addition, significantly greater maximum EMG activity and average EMG activity per sec was observed for thick pastes compared with liquids and thin pastes on all but one EMG measure. Other studies documented increased oral pressures produced by tongue to palate contact with heavier consistencies [4,5]. Increased oral pressures may be produced, in part, by increased activity of the submental muscles. Likewise, greater laryngeal elevation previously reported to be dependent on bolus consistency suggests the need for greater infrahyoid activity [2,8], the latter, a finding of the present study.

In contrast, the onset of the sound spike proved to be a relatively stable event across consistencies in this study. Other studies of the sounds of swallowing also reported easily identifiable signals, however, some disagreement exists regarding what these signals represent [9–16].

Finally, it was observed that the submental muscle activity initiated the swallow most often. Similar findings were reported previously [17–19]. It was proposed that the muscles in the floor of the mouth contract first to form a platform and provide support for tongue movements during the remainder of the swallow. The finding that the infrahyoid muscle activity most frequently terminated the swallow is supported by Shaker et al. [8] who defined laryngeal descent as one of the last events to occur in the swallow.

Coster et al. [20] stressed the importance of assessing the rheological characteristics of boluses for determining a "swallow-safe" bolus. A scale of consistencies from Newtonian fluid, viscoelastic fluid, viscoelastic solid, to elastic solid, and heterogeneous food (those foods having both fluid-like and solid-like material) was presented and the difficulty of assessing bolus properties such as viscosity, elasticity, and fracturability was discussed.

Later, Li et al. [21] published their results of the first systematic measurement of barium-sulfate mixtures. They established standards of low-, mid-, and high-viscosity samples and precise procedural guidelines for measurement. More importantly, Li et al. documented significant differences in viscosity as the result of seemingly slight variations in mixture ratios, changes in bolus temperature, and bolus settling. Unfortunately, the effects of these precisely measured boluses on swallow events were not assessed.

Although some significant differences between the thickest and the two thinner food categories were observed, overall, the two thinner food categories failed to result in significantly different effects. This result suggests that subjective judgment of differences in consistency is not always valid and emphasizes the need to quantify rheological characteristics of boluses used in future studies. In this way, foods can be correctly classified and their effect(s), if any, on the swallow can be documented.

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