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Dysphagia

Effects of Mechanical, Cold, Gustatory, and Combined Stimulation to the Human Anterior Faucial Pillars

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Abstract. Tactile–Thermal Application (TTA) is a therapy technique designed to enhance the swallowing response in persons with dysphagia. In this study, TTA was broken down into each component stimulus (i.e., Cold, Mechanical, Gustatory), and all combinations thereof, to study the effects of each condition on measurable parameters of the normal human swallow response. Using surface electromyography (EMG), latency to swallow-specific activity and duration of submental EMG activity were measured to examine the following questions: (1) Are there stimulus-dependent differences in onset latencies and contraction durations of the submental muscle activity? (2) Which stimulus components are responsible for this response? (3) How long do the effects of stimulation last on the response? (4) Are there response differences according to age and gender? Between-subjects multivariate analysis of variance showed that the main effects for Treatment, Gender, and Age were significant. Latency to swallow-specific activity was significantly shorter following Mechanical + Cold + Gustatory condition compared to No Stimulation. The effect of stimulation on the swallow response lasted for only one swallow.

Key words: Anterior faucial pillar — Dysphagia — Deglutition — Electromyography — Mechanical stimulation — Thermal stimulation — Gustatory stimulation — Deglutition disorders.

Individuals with cortical damage often demonstrate a delayed pharyngeal swallow response, defined as an increased time between the arrival of the head of the bolus at the posterior margin of the ramus and the beginning of the maximum elevation of the hyoid bone during the swallow [1,2]. Because the pharyngeal swallow response is associated with a cascade of airway-protective events, its delay places patients at an increased risk for aspiration or choking. Dynamic or mechanical stimulation administered to the mucous membranes in the oral cavity has been used in the clinical setting since 1956, presumably to aid in the initiation of the human swallow response [3]. Anecdotal reports of gustatory and cold stimulation presented to the oral mucosa also can be found in the dysphagia literature as early as 1972 and 1979, respectively [4,5]. Although the pharyngeal swallow response can be triggered from a variety of sites along the upper alimentary tract [6–8], the anterior faucial pillars have received particular attention for dysphagia intervention [9–11]. Combined tactile and thermal application (TTA) to the anterior faucial pillars has been used clinically to hasten the pharyngeal swallow response in neurologically damaged persons who demonstrate a delayed swallow initiation, although the efficacy of this strategy and its long-term success remain to be proven [12].

Despite the clinical popularity of TTA (and other stimulation techniques), current practice protocols are not derived from solid physiologic evidence

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for stimulation sites or stimulus characteristics. Instead, the profession draws from a relatively recent history of clinical impressions; a diverse literature on swallow elicitation physiology in normal humans and other animals [13–23]; and a limited, but growing, number of studies of mucosal stimulation in neurologically disordered populations [4,5,10,12,24]. These latter studies, in particular, have produced no clear evidence for a sustained facilitative influence of peripheral stimulation on swallowing. Although our inability to generate firm support for TTA may suggest the technique is not efficacious, it may also reflect the multitude of variables inherent in stimulation techniques that have yet to be systematically explored (e.g., see Rosenbek et al. [24] who evaluated the variable of treatment intensity in an efficacy paradigm).

The primary stimulus components of TTA are cold temperature (thermal), dynamic mechanical deformation (tactile), and, in some clinical settings, flavor (gustatory). The most systematic investigations of the contribution of these variables, particularly temperature, on measures of swallow initiation have come from studies of normal, healthy volunteers. Kaatzke–McDonald et al. [23] studied the variables of temperature (cold versus tepid), touch (three strokes to the anterior faucial pillars versus feigned stimulation), and taste (glucose versus saline) in ten healthy females. Using laryngographic measures, they found that only cold touch stimulation evoked a significant decrease in swallowing latency, supporting the idea that the human faucial pillar contains cold-sensitive receptors. However, at least two other studies refute these findings. Knauer et al. [25] found no manometric change in upper esophageal sphincter–pharyngeal timing relationships in response to cold stimulation in their healthy volunteers. Ali et al. [13] found no manometric or videoradiographic changes with either the application of cold or local receptor blockade of the anterior faucial pillars in their healthy participants.

There are a number of possible explanations for the discrepant findings with regard to temperature. Logemann's original protocol of "chilling a laryngeal mirror in ice" [11, p.136] prior to stimulation is useful for ease of clinical application. However, Selinger et al. [26] have shown that a metal probe encased in an insulator made of ceramic is perceptibly neutral within six seconds after removing it from the ice. The rapid increase in temperature of common metal probes would virtually prohibit their use in any controlled study of the effects of cold application on swallowing.

An argument could also be made against the use of healthy volunteers to explore the stimulus components of TTA. It may be the case that their nondelayed pharyngeal swallow responses are at some physiologic ceiling. However, physiologic studies in normal humans and other animals have demonstrated that intersensory interaction of peripheral and central inputs differentially affects the swallow response.

Researchers have examined intersensory interaction by presenting combinations of sensory stimuli to the cortical and peripheral regions in animal and human studies. Much of the animal research has applied electrical stimulation to the peripheral nerves and regions of the CNS while measuring muscular responses [15–18]. Others have applied more common stimuli, such as mechanical (touch), chemical (taste), and thermal (cold/warm), to the oropharyngeal mucosa while monitoring muscular and neuronal responses in decerebrated animals [19,20]. More recently, electromagnetic stimulation of the cortex and peripheral nerves in healthy human subjects has shown that cortical swallowing pathways can be modulated by cranial nerve afferent stimulation [21,22]. These studies collectively have shown that intersensory interaction in swallowing does occur under experimental conditions, and they lend support to its study in neurologically normal populations.

The purpose of the present study was to systematically explore three stimulus components, individually and in combination, that may influence the pharyngeal swallow response: temperature (cold vs. ambient), taste (sour vs. no flavor), and form of mechanical stimulation (dynamic vs. static). To our knowledge, this is the first study to use a specially constructed probe to ensure constant and uniform temperature across trials and subjects and to deliver a constant amount of sour flavor across trials and subjects. Surface EMG of the submandibular musculature was selected as an indicator of swallow-specific muscular activity, and a water infusion system was used to deliver the bolus at a constant rate following stimulation. Latency to swallow-specific activity and duration of submental EMG activity were measured to examine the following questions: (1) Are there stimulus-dependent differences in onset latencies and contraction durations of the submental muscle activity? (2) Which stimulus components are responsible for this response? (3) How long do the effects of stimulation last on the response? (4) Are there response differences according to age and gender?

Methods and Procedures

Subjects

Fourteen healthy volunteers, young (Age range = 21–32 years, mean age = 25.4 ± 3.5, three males and four females) and old (range = 67–80, mean age = 70.1 ± 4.2, three males and four females), participated in the study. The following criteria were used to screen volunteers via self-report: (1) good health; (2) no history of any neurologic, otolaryngologic, and/or respiratory disorders; (3) no history of dysphagia; (4) no insulin-dependent diabetes mellitus; (5) no history of smoking within one year of study; (6) clean shaven under the chin; (7) not taking any medications that could affect swallowing function (e.g., phenothiazines); (8) no hyperactive gag reflex to ensure comfortable participation in the entire experimental protocol; and (9) no ingestion of caffeine or spicy foods six hours before the study in order to minimize chemical influences on the oropharyngeal mucosa [23]. A total of 20 subjects were screened, 5 were not used because of self-reported discomfort with oral stimulation and 1 was excluded prior to the start of the study due to a hypersensitive gag response. A total of 14 subjects participated in the experimental protocol. Subjects gave informed consent in accordance with policies and procedures at Arizona State University. The data for one elderly female could not be used when it was determined that she had been actively sucking water out of the straw, thus changing the rate and volume of the water delivery.

Instrumentation

Surface Electromyography

Selecting a single measure that corresponds precisely with the onset of swallow initiation (i.e., the pharyngeal swallow response) is a challenge in swallowing research. Though historically regarded as fixed and involuntary, the pharyngeal swallow response is characterized by an array of oral, pharyngeal, velopharyngeal, laryngeal, and upper esophageal events whose sequences and timing show significant variability [2,7,8]. In other words, we know of no single "first event" of the pharyngeal response that occurs without variation across individuals and swallowing situations. Therefore, any single indicator must be regarded only as an estimate of pharyngeal response initiation, presumably reliably so within subjects and within controlled swallowing situations.

We chose submental surface EMG in the present investigation as an indicator of swallow-specific onset activity for two reasons. First, a burst of submental EMG activity associated with the swallow is thought to measure the combined activation of the paired geniohyoid, anterior belly of the digastric and mylohyoid swallowing musculature for posterior propulsion of the bolus. This "leading complex" of muscles participating in the swallow sequence has been regarded as a valid approximation of pharyngeal response initiation [27]. Although evidence exists that the "leading complex" may not always be the first event of the pharyngeal response [28], particularly in the context of mealtime eating [8], there is evidence of its more consistent relationship with other components of the pharyngeal response in controlled swallowing situations. Perlman et al. [29] examined the durations and temporal relationships of EMG activity from the submental complex, superior pharyngeal constrictor, cricopharyngeus, thyroarytenoid, and interarytenoids using hooked-wire and surface electrodes and confirmed earlier findings that submental EMG activity was < 45 ms preceding the onset of superior constrictor activity.

The second reason for choosing this measure relates to the reliability with which it could be identified and measured. The time history of submandibular muscle activity necessarily reflects oral preparatory, bolus transit, and pharyngeal swallow-related activity in the EMG record. During the preliminary stages of this investigation, it was verified that the EMG bursts associated with observed swallows were visually robust and readily distinguishable from low amplitude background activity (see interjudge reliability measures below). That is, the observed swallows corresponded with distinct and discrete bursts of EMG activity whose shapes were consistent and similar across swallows within subjects. Though not verified via visualization techniques, these abrupt EMG bursts associated with the swallow event likely encompassed the abrupt posterior tongue elevation associated with bolus propulsion, and the subsequent phase of hyolaryngeal elevation that also recruits the submandibular musculature.

Two disposable ECG surface electrodes (Blue Sensor, Medicotest, Inc. type M-00-S), were placed to the right and left of midline on the submental complex with an interelectrode distance of 4 cm. The reference electrode was placed on the subject's clavicle bone. The EMG data were collected using a telemetry EMG system (Telemy, Noraxon, USA, Inc., Scottsdale, AZ). The sampling frequency rate was set at 1000 Hz for 30 s. A linear envelope of the EMG activity of the submental complex and the spike signaling water infusion (described in procedures) were monitored on-line during recording. The raw EMG profiles were then analyzed using software written in Matlab (The MathWorks, Inc., version 5.1.0.421, 1997). The EMG profiles were full-wave rectified and filtered using a fourth-order, low-pass, Butterworth filter, zero phase lag, with a cutoff frequency of 6 Hz.

Water-Infusion Pump

Previous studies of timing parameters following stimulation have presented premeasured barium boluses via a spoon or syringe while making measurements on videofluoroscopy [9,10,13]. Specific time measurements could be made according to when the barium bolus transcended specific anatomical markers on the dynamic radiographic image. Because of the use of submental EMG in the present investigation, it was necessary to devise a method for bolus delivery that permitted a precise marker of bolus administration. A Baxter INFUS O.R.ϑ water-infusion pump (Baxter Healthcare Corporation, Deerfield, IL) delivered room-temperature water, via a pipette placed in the corner of the mouth, onto the tongue dorsum. Water infused at a slow continuous rate of 0.5 mL/s for a total of 30 s following each application of stimulation. This form of bolus delivery was selected to precisely capture the onset of water infusion relative to the EMG activity and to provide a standard flow rate between and within subjects throughout the experiment. In the present study, an experimenter simultaneously began water infusion and separated two EMG leads to create an abrupt spike on an EMG trace. This served as the location of the leftmost marker from which latency to swallow-specific activity was measured.

Probes

Two identical probes were constructed specifically for use in the study. The probes were made of aluminum, a material that is nontoxic, lightweight, an excellent heat conductor, and maximizes specific heat capacity (Cp) and density, thus maintaining temperature over time. Each probe was 8 5/8 in. in total length, 4 1/8 in. from base to handle, and 4 1/2 in. from handle to tip. The handle, 5/8 in. in diameter, was covered in vinyl tubing to thermally insulate the probe during handling. The tip, 1/2 in. in diameter, had small holes drilled into it to hold drops of 100% Real Lemon Juice for the Gustatory condition. A thermistor was inserted into the base of the probe to monitor the temperature throughout the experiment. One probe was cooled to 8°C during the cold conditions while another probe remained at room temperature (25°C) for the ambient conditions. A bench study[1] showed an average temperature increase of 1.02 ± 0.20°C and 0.45 ± 0.09°C, following 10 s of direct contact to the oral mucosa for the cold and ambient probes, respectively.

Procedures

Subjects were seated comfortably in a high-backed, cushioned chair for the duration of the study. Subjects were prepared for surface EMG by shaving and abrading the skin under the chin and a bony area on the clavicle using a razor. The areas were then rubbed with a gauze pad soaked in alcohol. A pair of surface electrodes was placed under the chin following palpation of the muscle mass during a swallow. A ground electrode was placed on the prepared area on the clavicle. Electrode placement was secured with additional flexible tape.

Each session began with an overview of the study protocol, without divulging information about the purpose of the experiment. Several practice trials of mechanical stimulation to the anterior faucial pillars were provided to familiarize the subject with procedure and to reduce apprehension. When the subject reported feeling comfortable with the procedure, the experiment began.

The experimenter (first author) and an assistant collected all data. Each trial consisted of 10 s of stimulation (or no stimulation) and 30 s of water infusion. Trials were separated by three min of rest. The only variation between subjects was the predetermined order of conditions. For each trial, the experimenter held the subject's tongue down with a tongue depressor and moved the probe up and down 5 s on each anterior faucial pillar (or movement without touching for the No Stimulation condition). The subject were instructed to sustain an "ah" throughout the duration of stimulation to attenuate the gag reflex and ensure that no swallows occurred during the stimulation. As the experimenter administered the stimulation, she counted aloud from 1 to 10 (5 s for each anterior faucial pillar). When she reached the number 7, the assistant began the submandibular surface EMG collection in one channel. When the experimenter reached the number 10, the assistant simultaneously began the water infusion with one hand while separating two electrodes held together in the other hand. This created a spike in the second EMG channel from which to measure latency to swallow-specific activity. The subject then swallowed when it "felt natural" to do so and the EMG recording was stopped 30 s after the onset of water infusion.

Experimental Design

A repeated-measures design was used in which each subject was administered each of the eight conditions, repeated four times, for a total of 32 treatments. The 32 treatments were randomly assigned to each subject.

1. **No Stimulation (No Stimulation)**, defined as moving the probe within the oral cavity without touching any structures.
2. **Cold stimulation (Cold)**, defined as statically touching a probe (8–9.02°C) to each anterior faucial pillar for 5 s.
3. **Gustatory stimulation (Gustatory)**, defined as statically touching an ambient probe (25–25.45°C) dipped in 100% Real Lemon Juice to each anterior faucial pillar for 5 s.
4. **Mechanical stimulation (Mechanical)**, defined as dynamically moving an ambient probe (25–25.45°C) rapidly against each anterior faucial pillar from the base to the midline for 5 s.
5. **Mechanical + Cold (M + C)**
6. **Mechanical + Gustatory (M + G)**
7. **Cold + Gustatory (C + G)**
8. **Mechanical + Cold + Gustatory (M + C + G)**

Data Analysis and Reduction

A total of eight swallows had to be thrown out of the overall analysis of 416 swallows for the following reasons: inability to identify a swallow-specific EMG burst (4), equipment malfunction (2), and skipped during the experiment (2).

Multivariate, between-subjects and within-subjects, analysis of variance (MANOVA) for repeated measures was used to analyze the data using SPSS statistical software version 9.0.1. *Post hoc* comparisons among the eight conditions were explored using Tukey's HSD test. A *t*-test for equality of means was used to further analyze the No Stimulation and Mechanical + Cold + Gustatory (M + S + G) conditions. All statistical testing employed a two-sided alpha level of 0.05 for statistical significance. Power for the analysis of variance to detect a 1.00 difference between group means with the current sample size was 0.942.

The amplified, rectified, and filtered EMG profiles were displayed in three windows (see Fig. 1). Because it was found that each subject produced a fairly stereotypical EMG pattern for the swallow-specific burst, a prototypical example was displayed in the top window as a referent. Judges were able to compare the 30 s of EMG trace displayed in the second window with this referent to identify the swallow-specific bursts. The third window, time-locked with the second, contained the spikes associated with the onset of water infusion.

Although the swallow-specific activity and water infusion onsets were visually distinct, operational definitions were developed to ensure consistency of measurement and cursor placement. Swallow-specific activity was defined as a burst of motor activity above baseline activity. For swallow-specific activity onset, the cursor was placed at the first point in the swallow-specific activity burst that was 50% above baseline activity. Baseline was measured as the resting EMG activity prior to swallow-specific EMG activity. The swallow-specific offset was the first point that returned back to baseline. The onset of water infusion was defined as the first point 10% above the flat signal that was created by holding the electrodes together. Figure 1 contains examples of cursor placement for each of the following two measures:

1. *Latency to swallow-specific activity* measured from the water infusion spike to the onset of the swallow-specific EMG activity in seconds.
2. *Duration of submental EMG activity* measured from the onset and offset of swallow-specific EMG activity for each swallow in seconds.

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[1] Shane Olafson, B.S., Biomedical Engineering, ASU completed bench study as part of his senior project.

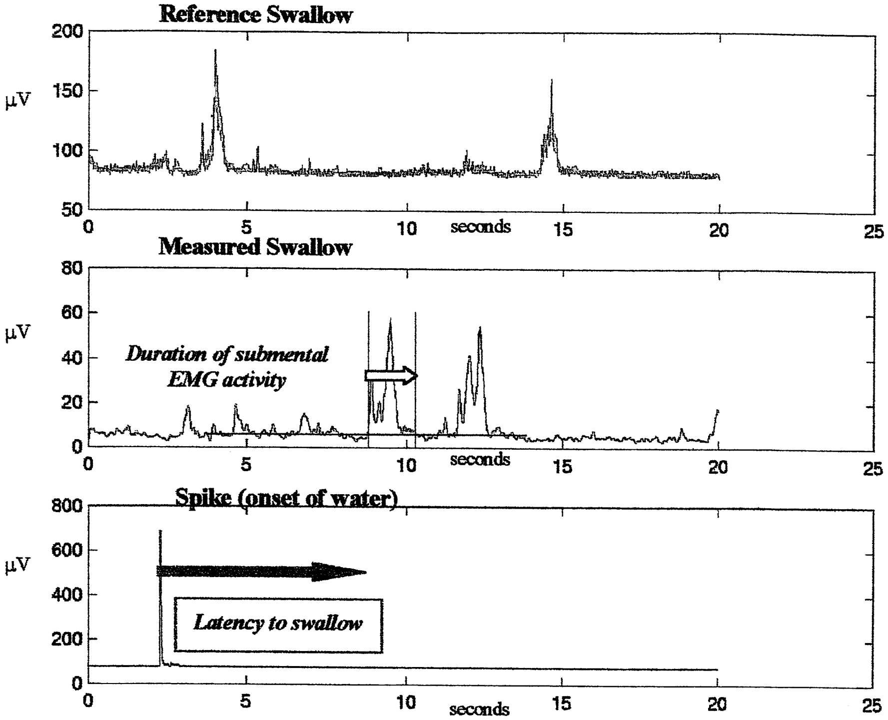

Fig. 1. Example of measurements and events. (**Top**) A subject-specific referent EMG burst associated with swallow-related activity. (**Middle**) The rectified EMG signal and cursors marking the duration of submental EMG activity. (**Bottom**) (Time-locked with the middle panel) Spike marking the onset of water infusion and the cursor marking latency to swallow-specific activity.

Interjudge Reliability

A second trained judge repeated all measurements for one randomly selected subject (Subject 5), and these values were used to calculate the extent of interjudge agreement. A point-to-point correlation was made for the two sets of measurements and these values were deemed acceptable for interjudge reliability. The average correlations for the measurements *duration of submental EMG activity* and *latency to swallow-specific activity* were 0.822 and 0.835, respectively.

Results

Overall Statistical Analysis

Results from the between-subjects and within-subjects MANOVA are displayed in Table 1. The between-subjects MANOVA results were significant for Treatment, Gender, and Age. A significant main effect for Treatment indicates that statistically different EMG values overall were observed for all subjects following the 8 Treatment conditions. Main effects for Gender indicate that dependent measures were statistically different overall between males and females. Main effects for Age indicate that young and old subjects had statistically different overall EMG parameters. Between-subject interaction effects were not significant. The within-subjects MANOVA examining Trial by Treatment, Age, Gender, and all combinations thereof, was not significant ($p = 0.284$). Following the multivariate analyses, univariate analysis of variance (ANOVA) and *post hoc* examinations were completed to determine the effect of the treatment conditions on each of the variables measured: *latency to swallow-specific activity* and *duration of submental EMG activity*. Univariate ANOVA examined each of the dependent variables to delineate specific differences according to Age and Gender.

Latency to First Swallow Specific Activity

As can be seen in Table 2, stimulation had a noticeable effect on latency to first swallow initiation. The Tukey HSD procedure showed that the overall statistical analysis among means on the measure of *latency to swallow-specific activity* was not significant ($p = 0.054$). The Tukey HSD pairwise comparisons listed in Table 3 show a significant difference comparing mean values for *latency to swallow-specific activity* between the smallest mean (M + C + G)

Table 1. Repeated measures between-subjects and within-subjects MANOVA for all subjects

Source	*Df*	*F*	*p**
Between subjects			
Treatment (T)	21	1.853	0.017*
Gender (G)	3	8.756	0.000**
Age (A)	3	4.932	0.004**
T × G	21	0.334	0.998
T × A	21	0.231	1.000
G × A	3	1.638	0.190
T × G × A	21	0.261	1.000
Within subjects			
Trial × Treatment (T)	63	1.107	0.284
Trial × Gender (G)	9	0.409	0.925
Trial × Age (A)	9	0.822	0.599
Trial × T × G	63	0.913	0.661
Trial × T × A	9	0.877	0.732
Trial × G × A	9	1.67	0.118
Trial × T × G × A	63	0.529	0.999

Wilk's lambda $*p < 0.05$; $**p < 0.01$.

Table 2. Latency to swallow-specific activity (seconds) by treatment condition

Treatment condition	Mean	SD	*N*
No Stimulation (NS)	9.000	1.308	13
Cold Stimulation (C)	4.068	1.433	13
Gustatory Stimulation (G)	5.290	1.393	13
Mechanical Stimulation (M)	5.052	1.472	13
M + C	6.540	1.393	13
M + G	5.206	1.393	13
C + G	3.763	1.308	13
M + C + G	2.914	1.393	13

and the largest mean (No Stimulation) ($p = 0.045$), with no other significant pairwise results. This result indicates that only the treatment condition that employed all three types of stimuli together resulted in a significantly quicker average initiation of swallow activity when compared to the No Stimulation condition. All other treatment conditions did not result in a statistically quicker average swallow activity compared to No Stimulation.

Duration of Submental EMG Activity

A univariate ANOVA for repeated measures was conducted and the main effect of stimulation on *duration of submental EMG activity* was not significant ($p = 0.972$). The Tukey HSD revealed that the overall differences on mean *duration of submental EMG activity* among treatment conditions was not significant ($p = 0.122$), and no pairwise comparisons were significant. The duration of submental EMG activity was, therefore, not significantly affected by the different treatment conditions but rather remained fairly stereotypical across conditions.

Table 3. Tukey HSD comparing **No Stimulation** to each of the treatment conditions

Treatment	Mean difference	SE	*p**
Cold (C)	4.787	1.92	0.216
Gustatory (G)	3.924	1.87	0.430
Mechanical (M)	3.548	1.92	0.589
M + C	2.339	1.87	0.914
M + G	3.681	1.87	0.513
C + G	5.321	1.84	0.090
M + C + G	5.945	1.87	7.045*

Studentized t, $*p < 0.05$.

Time Between First and Second Swallows in NS and M + C + G Treatment Conditions

Because water infusion occurred at a constant flow rate for 30 s following application of the stimulation, many instances of a second swallow were captured in the EMG records. That is to say, water infusion began at time zero, a first instance of swallow-specific activity was recorded prior to 30 s, water infusion continued, and a second instance of swallow-specific EMG activity was recorded before the 30-s epoch was concluded. This provided an opportunity to explore whether there was evidence for sustained effects of the M + C + G condition on latency to swallow-specific activity. To accomplish this *post hoc* analysis, the *average time between the 1st and 2nd swallows* was calculated for the No Stimulation and M + C + G conditions. The measurement was taken from EMG offset of the first swallow to the EMG onset of the second swallow. It was hypothesized that the average latencies between first and second swallows would be shorter in the M + C + G than in the No Stimulation condition if the neurophysiological system remained "upregulated," as documented in previous research [9]. Of the 52 potential opportunities for a second swallow-specific event in each condition, the No Stimulation condition contained 35-s swallows and the M + C + G condition contained 45-s swallows. The t-test for equality of means for the *average time between the 1st and 2nd swallows* for the two treatment conditions for all the subjects was not significant ($p = 0.916$). This result indicates that

Table 4. Average time between the first and second swallows (seconds) following stimulation for the NS and the M + C + G treatment for all subjects

Treatment	Mean	SD	*T*	*p**
NS	5.751	2.019	−0.107	0.916
M + C + G	5.843	2.254		

*$p < 0.05$.

M + C + G stimulation caused a decrease in latency to swallow-specific activity on the first swallow following stimulation only, with the response time of the second swallow returning to the baseline response time. Table 4 summarizes the results.

Age

As can be seen in Table 5, there are significant differences according to Age on the averaged measure *latency to swallow-specific activity*. Results from the between-subjects MANOVA for Age were significant ($p = .004$). Univariate analyses were significant for *latency to swallow-specific activity* ($p = 0.02$) but were not significant for *duration of submental EMG activity* ($p = 0.144$). These results indicate that the older subjects in this study on average had a significantly shorter latency to swallow activity initiation than the younger subjects.

Gender

Table 6 shows the significant differences according to Gender on the averaged measure of *duration of submental EMG activity*. Results from the mulitivariate between-subjects ANOVA for Gender were significant ($p = 0.001$). Univariate analyses were significant for *duration of submental EMG activity* ($p = 0.044$) but were not significant for *latency to swallow-specific activity* ($p = 0.228$). Female subjects in this study on average had a significantly longer duration of swallow activity than the male subjects. Results indicate that there was no difference in latency to swallow-specific activity according to Gender.

Discussion

This study examined the different sensory modalities that have been used to stimulate the anterior faucial pillars (Mechanical, Cold, Gustatory) applied alone and in all combinations, while examining submental muscle activity with surface EMG in healthy old and young subjects, male and female. There were no differences in EMG duration among the conditions. However, the condition that combined all three sensory stimuli (M + C + G) was associated with the shortest *latency to swallow-specific activity* as compared to No Stimulation. This quicker swallow-specific activity occurred only on the first swallow following stimulation, returning to baseline response time on the second swallow. These findings support the explanation of a temporary facilitative effect of this stimulus combination on swallow-specific activity in these normal healthy volunteers. These results, along with significant between-subject age and gender findings, will be discussed.

Table 5. Latency to swallow-specific activity and EMG duration by age

Measure	Age	Mean	SD	*F*	*p**
Latency to response (s)	Old	4.063	0.717	5.651	0.02*
	Young	6.395	0.670		
EMG duration (s)	Old	2.132	0.104	2.185	0.144
	Young	2.342	0.097		

*$p < 0.05$.

Table 6. Latency to swallow-specific activity and EMG duration by gender

Measure	Gender	Mean	SD	*F*	*p**
Latency to response (s)	Female	4.631	0.670	1.485	0.228
	Male	5.827	0.717		
EMG Duration (s)	Female	2.383	0.097	4.238	0.044*
	Male	2.091	0.104		

*$p < 0.05$.

Neurophysiologic Theories

Several theories about the neurophysiological mechanisms responsible for the alteration in swallow response time have been proposed. One possible level of explanation is in the alteration of receptor characteristics secondary to the application of a stimulus. Thermal and tactile stimulation of the anterior faucial pillars may upregulate the mucosal receptors, thus lowering the threshold to evoke the subsequent pharyngeal swallow [9,13]. A second hypothesis is that stimulation to the anterior faucial pillars increases "oral awareness" thus serving as a higher-level alerting mechanism that facilitates the swallow response [11]. This theory would depend on the medullary swallow center to integrate cortical and peripheral inputs and modify motor events according to anticipated bolus properties. A third possible explanation is simply that the swallow response threshold remains unchanged; however, the summation of receptor activity in response to the greater sensory input leads to the quicker swallow response. All three theories credit the oropharyngeal sensory receptors in influencing swallow events. Although the present study was not designed to test these hypotheses, the results can be interpreted in light of them.

With regard to the explanation of upregulation, sensory input alters the permeability across the receptor membrane, known as the receptor potential, dependent on each receptor's shape and function. Mechanical deformation of the receptor stretches the membrane and opens ion channels, chemical contact opens the ion channels, and cooling of the mucosa alters the permeability of the membrane [30]. When the receptor potential rises to a certain threshold, the action potentials of the sensory afferent nerve fiber are elicited. The more the receptor potential rises above this threshold level, the greater becomes the action potential frequency [30]. Results from this study offer weak support for this physiological phenomenon. That is, the combined M + C + G condition stimulation may have effectively and temporarily altered the receptor potentials such that swallow-specific activity occurred sooner following water infusion than in the condition of No Stimulation. However, it would have been more compelling if the nature of the stimulus (mechanical, thermal, or gustatory) had emerged as a factor in this facilitative effect. Also, the fact that the effect was apparent only on the first swallow after stimulation in the M + C + G condition suggests a very temporary alteration at most.

The explanation of heightened oral awareness and higher-level influences on swallow behavior following stimulation is difficult to defend or refute with the current results. This point is an important one to consider, however. In this study and others, it is assumed that the effect of the stimulus applied to the oral mucosa must be the result of the stimulation's impact on "low level" mechanisms (i.e., cell, nerve, or brainstem nuclei). It is plausible that the effects also reflect the contribution of higher-level influences (heightened awareness or attention). This is particularly germane to investigators in the area of swallowing because swallow initiation, like breathing, can be completely under voluntary control, particularly when it is raised to levels of conscious awareness. It is unlikely that the results of the current study can be explained entirely by this hypothesis, however. If sensory stimulation, irrespective of type or quantity, has the potential to be facilitative simply by virtue of its alerting capabilities, we would have expected to see facilitative effects for all stimulus conditions as compared with No Stimulation. This was not the case.

Finally, the notion that the more sensory input the greater the summation and the more rapid the swallow response is weakly supported by the data of the present investigation. The facilitative and temporally local effects of the combined stimulation suggest that sensory input quantity may play a role. Again, however, more compelling support would have been found if we had seen some graded facilitative effect from No Stimulation to the combined conditions (e.g., latency-to-onset values decreasing from No Stimulation to single stimulus conditions, to two stimuli conditions, to combined condition).

Age and Gender Findings

The independent variables of Age and Gender were included in this investigation to parcel out their potential influences on the latency and duration results. This was based on previous research that has shown differences in muscle activation patterns and swallow measures in young versus old and male versus female subject populations [2,31–33]. Although Age and Gender differences were documented in the present study, their relationship to trends in previous reports is not altogether obvious.

The older group, on average, had a quicker initiation of submental EMG activity following water infusion onset than did the young group in this study. This is at odds with the well-documented observations that the majority of swallow-related measures among older people reveal slower and less efficient swallowing [2,31–33]. These include increased stage-transition duration, pharyngeal transit duration, duration to UES opening, and total swallowing duration [2,31,33]; and higher sensory thresholds in the pyriform sinus [32]. The reasons for our unexpected finding are not clear; however, it may be related to the relative good health and younger age of our subjects compared with those of previous studies (five of the seven were under the age of 70).

With regard to gender differences, females showed significantly longer durations of submental muscle activity than males, though latencies to onset were not different. One possibility is that the longer durations are related to the increased laryngeal elevation time necessary for prolonging the opening of the anatomically smaller UES. This is supported by the work of Robbins et al. [2], who found longer duration of upper esophageal sphincter opening in females, while all other measured parameters were equal between genders. The longer UES opening was attributed to female anatomy; a smaller UES would need to stay open for a longer duration to accommodate the passage of an equivalent bolus size. The submental EMG signal in the present study would capture sustained suprahyoid activity in the swallow-specific event.

Methodological Limitations and Caveats

The results of the present study are limited by a number of methodological considerations. First, we selected submental surface EMG activity as an indicator of the onset of swallow-related activity. Although this indicator is justifiable, other locations may have revealed different patterns of results. For example, sampling laryngeal elevation would have permitted a clearer demarcation between oral and pharyngeal stage components. This is not to say it is necessarily a more accurate or valid indicator of "pharyngeal stage onset," however. Gay et al. [28] demonstrated the rather soft assembly of activation patterns associated with laryngeal elevation and glottal adduction. Future investigations of the effects of sensory application to the pharyngeal response may choose to sample a variety of locations for a more comprehensive evaluation of the phenomenon.

Second, the present study utilized a slow, steady infusion of water as opposed to a bolus administration, and the instruction to swallow "when it feels natural to do so" rather than on command. As a result, bolus size was a direct function of latency-to-swallow. This has heuristic value in that less volume should be required to instigate the pharyngeal swallow when stimulation facilitates the response. However, these rather unique procedures limit comparability of our results with other published studies on submental EMG or on TTA. For example, Perlman et al. [29] instructed subjects to hold a bolus in the oral cavity until they were told to swallow. They measured the submental complex with surface EMG in normal subjects and found the following mean durations of muscle activation: saliva swallow = 0.847 s, 5-ml bolus = 0.731 s, 10-ml bolus = 0.795 s. This is significantly different from the average duration of submental activity in the current study, 2.237 s. Although the EMG bursts corresponded with observed swallows, our measures necessarily captured the onset of submandibular/lingual activity for posterior propulsion of the bolus, as well as the propulsion and hyolaryngeal elevation events. Again, studies that evaluate multiple levels and events associated with the pharyngeal response will permit greater scrutiny of procedural or methodological effects on data.

Finally, little can be said regarding clinical implications of the present findings because of the use of healthy, normal volunteers. However, the finding of a temporary facilitative effect of the combined stimulation on latency to swallow does provide indirect evidence for its potential influence in patients with dysphagia. Because the number of repetitions was so limited here as compared with the number shown to be most efficacious in treatment [24], the temporary nature of the effect must also be viewed with caution.

Future Research

As we evaluate treatment efficacy of TTA and other stimulation protocols, it is imperative that we simultaneously conduct research into the neurophysiological mechanisms responsible for the alteration in the normal and disordered swallow response. We need to determine ideal stimulus properties, such as temperature, taste, and intensity, for producing the greatest physiological changes. This study used probes cooled to 8–9.02°C. This temperature range was chosen rather arbitrarily because temperature ranges for exciting cold receptors in the anterior faucial pillars and other oropharyngeal structures in humans has yet to be determined. Cold can also be nociceptive. It is not known whether the quicker swallowing response in this study was due to activation of cold or nociceptive receptors.

Much of what we know about chemosensitive regions important for evoking the swallow response has come from animal research [19,20,34,35]. Similar research in human subjects is sparse [23,36]. Sour was selected for use in this study because it is a strong taste stimuli and clinical research has shown that it causes a quicker onset of the oral swallow in subjects with neurogenic dysphagia [37].

The ideal force to apply during stimulation has not been systematically studied. Fujiu et al. [38] provided mechanical stimulation to the anterior faucial pillar at a rate of 8 taps/s and a force of 0.4 N before and after application of topical anesthesia and found that the latency of glossopharyngeal-evoked potentials did not change, thus providing evidence for the importance of deep receptors in conveying mechanical sensation. Sweazey and Bradley [20] measured mean response frequencies of oral cavity and epiglottic neurons in the lamb nucleus tractus solitarius while increasing the strength of the mechanical stimuli (2–7 g) and found relatively small increases in response frequency with increases in stimulus strengths for both moving and punctate stimuli. Stimulation at 1 g, however, was less effective in eliciting neuronal responses.

Finally, it will be of great import to define the effects of sensory stimulation in different swallow situations, with different bolus characteristics. In particular, consecutive swallows or normal mealtime eating is a critical component to any future clinical design, as this will determine the practicality and value of this treatment strategy.

Summary

The most efficacious stimulus components for altering the human swallow response have not yet been delineated. The present study was the first of a series of studies that need to be conducted in order to study the effects of sensory input on the swallow response. This study was unique in that it controlled the mode of delivery of the stimuli while systematically altering temperature (e.g., cold vs. ambient), taste (e.g., sour vs. no taste), and form of mechanical stimulation (e.g., dynamic vs. static). Combining all the sensory stimuli applied to the anterior faucial pillars had a cumulative effect on altering the swallow response time. This study needs to be repeated in persons with dysphagia. The ability to develop treatment strategies more effectively to help individuals suffering from swallowing impairments depends upon continued research.

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