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Effects of olfactory and gustatory stimuli on neural excitability for swallowing

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ABSTRACT

This project evaluated the effects of olfactory and gustatory stimuli on the amplitude and latency of motor-evoked potentials (MEPs) from the submental muscles when evoked by transcranial magnetic stimulation (TMS). Sixteen healthy volunteers (8 males; age range 19–43) participated in the study. Lemon concentrate at 100% and diluted in water to 25% were presented separately as odor and tastant stimuli. Tap water was used as control. 15 trials of TMS-evoked MEPs triggered by volitional contraction of the submental muscles and volitional swallowing were measured at baseline, during control condition, during stimulus presentation, and immediately, 30-, 60-, and 90-min poststimulation for each of the four stimulus presentations. Experiments were repeated using the combined odor and tastant concentrations that most influenced the MEP independently. Differences in MEP amplitude measured during swallowing were seen at 30-, 60-, and 90-min poststimulation for simultaneous olfactory and gustatory stimulation as opposed to no differences seen at any point for stimuli presented separately. This study has shown that combined odor and tastant stimulation (i.e., flavor) can increase MEP amplitude during swallowing and that this enhancement of MEP can persist for at least 90 min following stimulation. As increased MEP amplitude has been associated with improved swallowing performance, a follow-up study is underway to determine the biomechanical changes produced by altered MEPs to facilitate translation of these data to clinical dysphagia management.

1. Introduction

The neural substrates controlling swallowing are divided into three components [1]: (a) the afferent system comprising the trigeminal, glossopharyngeal, and vagus cranial nerves; (b) the brainstem swallowing center, constituting a central pattern generator; and (c) the higher centers which modulate the swallowing response [partly through the efferent system]. The central pattern generator for swallowing consists of two main groups of neurons, the dorsal swallowing group containing the generator neurons and ventral swallowing group, which are also known as the switching neurons [2]. The dorsal swallowing group, with the nucleus tractus solitarius as a central component, accepts sensory information relevant to swallowing and then sends information to the ventral swallowing group, which includes the nucleus ambiguous. Motor output for swallowing is executed through this group [2].

The central pattern generator for swallowing in the brainstem can be modulated by inputs from the periphery and cortex [3]. This modulation might include olfactory (smell) and gustatory (taste) components of food that are under preparation for swallowing. Several studies have revealed a cortical role in initiating and regulating swallowing function [3–5]. The cortex receives inputs from afferent nerves, integrates these inputs with information stored in other cortical areas (such as the limbic system), and then sends that input to the central pattern generator to modify motor output that is optimal for the bolus that a person is preparing to swallow [6].

Fibers from the lateral precentral gyrus (motor strip) are known to project to the nucleus tractus solitarius and to the nucleus ambiguus [7]. These projections could play a role in swallowing, specifically during the voluntary, preparatory stage. Moreover, it has been reported that fibers from the cortex terminate in the pontine and medullary reticular formation [8], which may influence the muscles innervated by motoneurons from these areas. Thus, information from the cortex may excite or inhibit motoneurons in coordinating muscle movements during swallowing.

Prior research has shown that motor neurons can also be excited or inhibited by extrinsic sensory stimulation [9]. Electrical stimulation to the pharynx has been found to modify motor-evoked potentials (MEPs) from pharyngeal muscles and also found to modulate subsequent swallowing function [9]. Thus, we proposed that other forms of sensory stimuli, such as smell and taste, could produce a similar effect and may also influence swallowing. There are many published studies which have evaluated gustatory effects on swallowing biomechanics [10–19]

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but only two studies which have investigated olfactory effects [20,21]. Studies which have evaluated the underlying neural effects of olfactory and gustatory stimulation are even scarcer, with a single report documenting effects of gustatory input on neural transmission [22]. How olfaction and gustation affect swallowing neural substrates is an important clinical question given the current approach of utilizing sensory modulation of taste and smell for rehabilitation of patients with dysphagia [12,14,16,20,21].

Corticobulbar excitation of the muscles involved in swallowing can be evaluated by measuring the MEP in the submental muscles. This is a measure of neural excitability from the motor cortex to target muscles [23,24] in which single-pulse transcranial magnetic stimulation (TMS) is used to noninvasively evoke the motor potential. TMS does this by depolarizing neurons in the motor cortex which generates action potentials and, subsequently, an MEP in the muscle(s) represented by the stimulated region of the motor cortex. This evoked potential can then be recorded by electromyography (EMG). At low intensity, TMS can indirectly excite the neurons to fire [25] or induce current changes in the motor cortex [26]. Larger and earlier-onset MEPs can be recorded when a muscle is preactivated, as opposed to recording during a rest condition, as the neurons are in a more active state under this condition [26,27]. More importantly, preactivation of the muscle during elicitation of an MEP provides valuable information regarding the functional relevance of motor pathway activation.

Submental muscles, composed of the anterior belly of digastric, mylohyoid, and geniohyoid muscles, are involved in superior and anterior movements of the hyolaryngeal complex, an integral biomechanical component of bolus transfer and airway protection [28]. Treatment approaches such as the head lift [29] and Mendelsohn maneuver [28] frequently target the submental muscle group. Other researchers have also reported increased submental muscle activation when sour stimuli were presented [11,13,17].

This study aimed to investigate the effects of two concentrations of lemon odor and tastant on the excitability of the corticobulbar pathways controlling the submental muscles. We hypothesized that stimulation by either smell or taste would change the amplitude of the MEP recorded in this muscle group. Furthermore, we hypothesized that a higher concentration stimulus would produce greater MEP amplitude than a lower concentration stimulus as increased molecular concentration of the stimulus may excite more receptors, thus increasing neural excitation. It was also hypothesized that simultaneous presentation of odor and tastant would produce greater MEP amplitude compared to independent presentation of either stimulus as the convergence of flavor processing on the neural systems would increase excitation [30,31].

As increased neural excitability has been shown to increase muscle activation, elucidation of the neural effects of smell and taste may support development of rehabilitation approaches for swallowing impairment which involve presentation of sensory stimulation. This may offer significant opportunities, in particular, for patients in whom cognitive deficits inhibit participation in more behaviorally-focused rehabilitation programs.

2. Methods

A repeated-measures within-subject design was used to evaluate the effects of olfaction and gustation on the neural substrates underlying swallowing. MEP measures were taken during and after stimuli presentation and compared with baseline data.

2.1. Participants

Based on a priori power analysis using data from this lab [24], 16 participants (8 males, 19–43 years, mean age 25.5 years, SD 7.6) were recruited. An equal number of males and females were used, as the ability to identify odor was reportedly better in women than in men [32]. Young healthy adults were chosen as the laryngopharyngeal sensory threshold is increased in healthy adults greater than 60 years of age [33].

The participants were in good health with no previous history of neurological problems or dysphagia. They were nonsmokers for at least 1 year prior to the study and were not taking medication that could affect swallowing function. Subjects were asked to refrain from ingesting caffeine, alcohol, or spicy food during the 12 h prior to the study [18,19,34]. This was to ensure that no chemical residuals from food were present on the taste receptors, which might alter taste stimuli. All participants were informed of the procedures and written consent was obtained prior to the experiments. Ethical approval was obtained from the regional Health and Disability Ethics Committee.

2.2. Equipment

A Magstim 200 (Magstim Company Ltd, Whitland, Wales, UK) transcranial magnetic stimulator with a figure-of-eight coil was used to evoke MEPs in the submental muscle group. The novel approach to evoke MEPs during both volitional contraction and volitional swallowing [24], as opposed to earlier research in which the MEPs were evoked during the rest condition [22], was used in this study. Submental muscle contraction activated the transcranial magnetic stimulator for both conditions. Muscle contraction was detected with surface EMG (sEMG) using an amplifier (Dual Bio Amps, Model ML135, ADInstruments, Castle Hill, Australia) and a recording system (PowerLab 8/30, Model ML870, ADInstruments, Castle Hill, Australia) which were connected to a custom-built trigger system. A DeVilbiss PulmoMate® compressor/nebuliser (Model 4650I, Sunrise Medical, Pennsylvania) was used to present olfactory stimuli via nasal cannulas (Airlife™ Adult Cushion Nasal Cannula with 2.1-m Crush Resistant Supply Tube, Cardinal Health, McGaw Park, IL).

2.3. Stimuli

A pilot study was completed to identify lemon stimuli at high and low concentrations that were tolerated well, readily identifiable to participants as “lemon”, and subjectively reported to be substantially different in intensity. Visual analog scales were used for 7 participants to document subjective ratings of intensity, pleasantness, and tolerability after randomized presentations of stimuli. Six concentrations of lemon odor and tastant were selected from the same source (Country Gold lemon juice, Steric Trading Pty. Ltd., Villawood, NSW, Australia) with concentrations below 100% diluted in water. High (100%) and low (25%) concentrations were ultimately chosen for inclusion in the study. Both stimuli were readily perceived by all participants as lemon odor and tastant, and the low concentration stimulus was perceived as being substantially more pleasant than the high concentration stimulus. Both stimuli were tolerated well by all participants, with the 100% stimulus being less well tolerated than the 25% stimulus.

Participants were exposed to the nebulised odor stimulus through a nasal cannula inserted in both nares. They were asked to breathe as usual. Nebulised tap water was used as control. Olfactory stimuli were presented continuously for a minute, then paused for 15 s to avoid adaptation [35,36]. The stimulus was then presented again for another minute, and this was repeated until all MEPs were recorded (see Experimental procedures).

Filter paper (Genuine Whatman Filter Paper No. 5, W & R Balston, England) cut into 8-cm by 2-cm strips were used to present the gustatory stimuli [37]. Five cm strips of filter paper were soaked with either of the two gustatory stimuli (low or high concentration) and allowed to air dry. These were then placed on the surface of the tongue at midline with the 5 cm strip covering approximately two-thirds of the length of the tongue from the anterior tip. By using this