The Effects of Mouth Movements, Swallowing, and Spitting on Retronasal Odor Perception

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Received 20 January 1987

BURDACH, K. J. AND R. L. DOTY. The effects of mouth movements, swallowing, and spitting on retronasal odor perception. PHYSIOL BEHAV 41(4) 353-356, 1987.—Although attempts have been made to compare sensations produced by orthonasal and retronasal olfactory stimulation, previous studies have failed to address the dynamic nature of retronasal perception. In this study we demonstrate the importance of oral movements in influencing the perceived retronasal olfactory intensity. For orally-presented solutions of artificial orange and rum extract solutions, average magnitude estimates of eight subjects were significantly increased by various mouth movements (including spitting and swallowing) over a no mouth movement condition. These findings demonstrate that retronasal odor perception is a highly dynamic process, and suggest the hypothesis that mouth movements play a role in retronasal odor perception analogous to that played by sniffing in orthonasal perception. In addition, these data suggest that some disorders of deglutition may have associated chemosensory consequences.

Retronasal odor perception Flavor Olfaction Deglutition Swallowing Mastication Odor
Taste Tongue Gustation

COMPARED to orthonasal odor perception, little is known about the dynamics of retronasal odor perception. This is in spite of the fact that stimulation of the olfactory receptors by foods and beverages via the retronasal route is a primary determinant of their flavor and that persons who have lost their sense of smell frequently perceive the loss as one of taste, rather than as one of smell [4, 17, 20].

In informal experiments we have noticed that the flavor intensity of food substances appears to increase during chewing and swallowing. If this is generally true, such movements may be viewed as retronasal analogs to the sniffing movements of orthonasal odor perception, in that they influence the number of stimulus molecules reaching the olfactory neuroepithelium. To our knowledge, the extensive physiological literature on mastication and deglutition concerns itself mainly with neurological pathways involved in the swallowing process, and makes no mention of potential influences of these behaviors on chemosensory function (e.g., [21]). Indeed, the sensory aspects of deglutition have been restricted to the tactile stimulation involved in triggering the pharyngeal reflex.

The few published scientific studies of retronasal odor perception have focused on the relations between olfactory and gustatory perception (e.g., [1, 2, 10, 18]) or between orthonasal and retronasal perception (e.g., [2, 19]). However, these studies are limited in that the dynamic nature of retronasal odor perception was not addressed. Thus, if mouth movements greatly alter the olfactory sensations produced by materials inside the oral cavity (e.g., by increasing the number of stimulus molecules reaching the olfactory receptors), meaningful comparisons of orthonasal and retronasal odor sensations may require the standardization of oral movements.

The purpose of the present study was to empirically examine the influences of active oral processes on the retronasal perception of odor intensity. The results of this work indicate that masticatory movements are critically important for such perception and imply that pathological al-
terations in deglutition may have chemosensory conse-
quences.

METHOD

Subjects

Eight college students (median age=18 years), half of each sex, participated in the study. All reported being healthy at the time of their participation and none had any known problems with chemosensation.

Stimuli

Two commercially-available flavoring agents were used: imitation rum extract and imitation orange extract (McCormick & Co., Inc., Baltimore, MD). These substances were chosen because of their distinctive flavors and because they could be safely swallowed by the subjects. Since preliminary work showed that the orange extract produced stronger flavor sensations than the rum extract, we chose a slightly more dilute concentration of the orange extract (10^-3 vol/vol) than the rum extract (10^-2 vol/vol) for stimulus presentation. The rum and orange extracts were diluted in double-filtered deionized water and had as one component very low levels of ethanol (0.08% and 0.35%, respectively).

Experimental Procedure

Each subject provided magnitude estimates of the relative intensity of 6 ml of the two flavor extract solutions at each of four intervals: 5 seconds after placing a solution in the mouth with the nose held closed by the fingers and with no movement of the mouth parts; five seconds later following the release of the fingers; 10 seconds later following either no mouth movements or practiced "chewing-like" mouth movements; and 10 seconds later after either spitting out or swallowing the solution (see Table 1). The stimuli were presented in 30 ml plastic cups.

The same stimulus was used within a given trial sequence (Table 1). The subjects were instructed to rinse their mouth with deionized water after each sequence. The stimuli were presented in a randomized order. To stabilize the flavor intensity estimates, spitting, or swallowing were involved produced an enhancement of retronasal odor intensity. It is also apparent from this figure that the rum solution used in this study resulted in larger average intensity estimates than did the orange solution, even under the condition of no mouth movement. The statistical analyses, which are described below, confirm these general observations with only minor exceptions.

Since a free modulus method was used in this study, we

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<th>Trial Sequence No.</th>
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Estimates of retronasal odor intensity were made immediately following these behaviors (i.e., during the 2 seconds indicated before the initiation of the next condition). Each sequence was repeated 4 times for each of the flavoring agents to stabilize the intensity estimates, but only once for the distilled water condition. See text for details.

RESULTS

The dependent measure was the magnitude of the tape pulls following each of the time periods within the trial sequences summarized in Table 1. The median of the replications was used as the best estimate of each subject's response. Since magnitude estimates are typically log-normally distributed, the data were subsequently transformed to logarithms (base 10) before performing the parametric statistical analyses.

The mean log magnitude estimates (±SEM) following the conditions of no tongue movement, tongue movement, spitting, and swallowing are presented in Fig. 1 for both the orange and rum extract solutions. It is apparent that, for both flavoring agents, all of the conditions in which oral movement, spitting, or swallowing were involved produced an enhancement of retronasal odor intensity. It is also apparent from this figure that the rum solution used in this study resulted in larger average intensity estimates than did the orange solution, even under the condition of no mouth movement. The statistical analyses, which are described below, confirm these general observations with only minor exceptions.

Since a free modulus method was used in this study, we
normalized for modulus differences by using the intensity estimate during the nose open condition (Table 1) as the covariate in an analysis of covariance in which the tastant (orange, rum) and oral movement conditions (mouth movement, no mouth movement, spit, and swallow) served as repeated measurement factors (cf. [16]). In addition to the covariate, both the tastant and oral movement factors were statistically significant. F(1,6)(covariate)=10.01, p<0.02; F(1,7)(tastant)=19.27, p=0.003; F(3,21)(movement)=7.30, p=0.002. The tastant by oral movement interaction was not significant, F(3,21)=0.07, p=0.98.

Multiple comparisons among the means for the orange extract (see Fig. 1) demonstrated that the condition of no mouth movement differed from all other movement conditions (all df=7; mouth movement t=2.61, p=0.035; spitting t=2.29, p=0.056; swallowing t=2.99, p=0.02) and no other comparisons clearly differed from one another (mouth movement vs. spitting t=0.40, p=0.70; mouth movement vs. swallowing t=0.56, p=0.59; spitting vs. swallowing t=1.45, p=0.19). Analogous comparisons for the rum extract revealed the same general trend in which the no mouth movement condition resulted in lower intensity ratings than the other conditions (all df=7; mouth movement t=2.31, p=0.054; spitting t=1.71, p=0.13; swallowing t=2.77, p=0.03). Similarly, no meaningful differences were present in the mouth movement vs. spitting and the mouth movement vs. swallowing conditions (t=1.19, p=0.27; t=1.08, p=0.31). However, a significant difference did appear between the spitting vs. swallowing condition (t=4.08, p=0.005).

It should be noted that in the experimental design of the present study some of the experimental conditions which we compared did not occur at equivalent times within the 30 second time period (e.g., the spitting and swallowing conditions always followed the mouth movement conditions). However, this does not apply to the comparison of mouth movement vs. no mouth movement, or to the comparison of spitting vs. swallowing, which were temporally contiguous, indicating that temporal factors, per se, were unlikely the basis of the observed differences.

FIG. 1. Mean log magnitude estimates (±SEM) as a function of mouth movement condition for artificial orange and rum flavorings. See text for details.

DISCUSSION

The present study suggests that retronasal odor perception is a highly dynamic process, and that retronasal movement of molecules to the nasal epithelium is likely dependent upon air currents induced by active alteration of the musculature of the mouth and pharynx. Thus, just as sniffing can alter and presumably enhance the number of molecules reaching the olfactory region by the orthonasal route, it is likely that changes in tongue, cheek and throat movements can similarly influence the number of odorant molecules reaching the receptor region via the retronasal route.

A meaningful interpretation of the findings of this study requires an assessment of the processes which occur during mastication, deglutition, and expectoration. During mastication, the structure of solid foods is broken down and the surface area from which volatiles arise is greatly increased. During this process air-borne molecules are transported to the olfactory receptors both by passive diffusion and by active turbulent airflow arising from jaw and tongue movements (see [21]). Alterations in the temperature of the materials and their mixing with saliva presumably also influence these processes.

The next phase, deglutition, is considerably more complex and needs to be described in detail before we assess its influences on airflow patterns in the nasopharynx. Deglutition serves to transport food from the oral cavity to the stomach, and can be broken down (on the basis of cinefluorographic studies) into several phases [9, 11, 15]. During the "collection phase," the food is collected and formed into a bolus in the anterior region of the oral cavity while the pharyngeal part of the tongue contacts the posterior palate. In the "anterior alveolar phase," the tip of the tongue is placed against the anterior alveolar ridge (above the maxillary incisors). Simultaneously, the posterior part of the tongue is pressed down while the soft palate is elevated. During the "midpalatal phase" the bolus is moved towards the pharynx: the anterior part of the tongue presses first against the alveolar ridge and then against the frontal area of the hard palate. This movement is repeated various times until the food reaches the posterior region of the oral cavity. At this time, the soft palate closes the nasal passage, thereby preventing the advance of food into the nasopharynx. As the bolus reaches the soft palate, the "posterior compression phase" begins. The pharyngeal reflex is elicited, which results (among other effects) in a cessation of any voluntary motor activity within the oral cavity and in a complete interruption of respiratory functions. During this phase the posterior part of the tongue conveys the bolus into the pharynx. Then, during the "pharyngeal phase," the whole pharyngeal tube is elevated and the bolus is pressed into the esophagus by peristaltic movements of the pharyngeal constrictors. At the same time, the larynx opens, the epiglottis covers the laryngeal opening, and the laryngeal muscles contract to prevent the penetration of food substances into the trachea. After completion of these activities, the soft palate returns to its former position, opening again the passageway to the nasal cavity. The larynx is also reopened and respiration is restored.

For present purposes, the alterations in pressure which occur during the various phases of deglutition are of special interest, since they directly relate to the airflow patterns within the oral cavity, pharynx, trachea and esophagus. These variations in pressure are caused by the contraction of muscles, which result in transient changes of the volume of...
the hollow spaces during propulsion of the bolus. Manometric measurements show that during swallowing a slight increase in pressure takes place first within the oral cavity which is caused by muscular activity of the cheeks and lips [8]. This increase in pressure lasts until the pharyngeal phase is finished. The most dramatic rise in pressure during this phase, however, is observed in the hypopharynx [7]. Simultaneously, there is a slight increase of intratracheal pressure. Esophageal pressure, on the other hand, is kept near zero during the pharyngeal phase and increases when the bolus arrives at the esophagus. At this phase of deglutition the hypopharyngeal pressure returns towards zero because the nasal passage is reopened by the soft palate [12,13].

What are the probable consequences of these processes for retronasal odor perception during and after swallowing? As indicated earlier, the concentration of molecules is steadily rising within the oral cavity during the masticatory period. The concentration is further increased when the bolus is isolated in the posterior part of the oral cavity during the midpalatal phase. By the beginning of the pharyngeal stage the air above the bolus is highly compressed and saturated with odor molecules. After the termination of this phase, however, the bolus is separated from the surrounding air on its course into the esophagus. Most of the odorous air then likely ascends into the nasopharynx as soon as the soft palate returns to its original position, leading to intensive stimulation of the olfactory receptors within the nasopharynx.

To our knowledge, manometric measurements of the process of expectoration have not been performed. There is no doubt, however, that the physiological mechanism of this motor pattern is based on pressure generated within the trachea, larynx, pharynx, and oral cavity in order to expel the material from the mouth. As in the pharyngeal phase of deglutition, the soft palate closes the nasopharynx, and the airflow is directed through the oral cavity. Nevertheless, part of the air surrounding the bolus reaches the nasopharyngeal region after the nasal passage opens, possibly transported by the turbulence arising after the relatively fast decompression.

Although we have stressed the highly probable influences of oral movements on alterations in airflow patterns and the retronasal delivery of odorants to the olfactory receptor sheet, the possibility that at least some oral movements may influence olfactory function via neural pathways cannot be overlooked. There is both electrophysiological [23] and behavioral [3] evidence that stimulation of nasal trigeminal affereents may alter olfactory responsiveness. If true, it is conceivable that similar relations may exist between oral afferents and the olfactory system. To what degree, if any, such a process contributes to retronasal odor perception is not known.

In summary, our results suggest that diffusion alone is not very efficient in producing marked retronasal odor perception, since under both flavor conditions the lowest perceived intensity was experienced when no mouth movements were made. Indeed, mouth movements seem to be a major factor in determining the intensity of the retronasally perceived stimuli. However, considerably more work is needed on this point, since there are likely complex relations between the concentration of the stimuli and the importance of diffusion in determining the perceived retronasal odor intensity. It is of interest that the magnitude estimates of the more highly concentrated solution (rum) were generally larger than those for the less concentrated solution (orange) even under the condition of no mouth movement, in support of the hypothesis that diffusion may be less important for lower stimulus concentrations. Whatever the role of diffusion, however, the present findings indicate that mouth movements clearly produce an enhancement of retronasal odor perception and indicate that such perception is a highly dynamic process.

REFERENCES