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Swallowing Is Differentially Influenced by Retronasal Compared with Orthonasal Stimulation in Combination with Gustatory Stimuli

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Abstract

Identical stimuli are processed differently when presented ortho- or retronasally. In contrast to orthonasal olfaction, retronasal odorant perception is strongly associated with flavor and food intake, which is usually followed by swallowing. Along with other stimuli, gustatory stimuli are known to influence the swallowing reflex. It was therefore the aim of present study to examine whether retronasal olfaction, in combination with simultaneous gustatory stimuli, influences swallowing in a manner different from that of orthonasal olfaction. Fifty normosmic and normogeusic subjects took part in the study. A sweet taste (glucose, delivered via an intraoral taste dispenser) was presented simultaneously with vanillin, a food-like odor, either ortho- or retronasally at random using a computer-controlled olfactometer. Ultrasound imaging of the mouth floor was recorded on videotape to continuously monitor swallowing activity. After retronasal stimulation, swallowing occurred significantly faster (7.49 vs. 9.42 s; $P < 0.001$) and also took place more frequently compared with swallowing after orthonasal stimulation (1.38 times vs. 1.14 times; $P < 0.001$). These results show that a food-like odorant presented retronasally in combination with a congruent taste stimulus can influence swallowing. Whether these results can be assigned to other, unfamiliar, unpleasant nonfood-like odors has yet to be determined.

Key words: retronasal odorant perception, swallowing, taste, ultrasound

Introduction

Odorants presented orthonasally are perceived differently from those presented retronasally. It is known that odorants of the same intensity are perceived as less intense when applied retronasally compared with orthonasally (Heilmann and Hummel 2004). Moreover, retronasal thresholds of odorant sensations are typically higher than orthonasal thresholds. These and the following findings support the idea that processing of ortho- and retronasal odorants differs even when stimuli are identical in concentration and hedonics (for review, see Small and Prescott 2005; Hummel et al. 2006). This difference in processing has been demonstrated using olfactory event-related potentials (Hummel and Heilmann 2008) and functional magnetic resonance imaging (fMRI) (Small et al. 2005). Specifically, results from an fMRI study found greater activation in the mouth area at the base of the central sulcus in response to retronasal compared with orthonasal perception of a chocolate odor (Small et al. 2005). The authors suggested that this preferential response reflected olfactory referral, by which a retronasally sensed odor is referred to the mouth (Murphy et al. 1977). Apart from experimental conditions, retronasal odorant stimulation takes place during food intake and is therefore often mistaken as taste. In addition, taste influences odor perception and vice versa (Welge-Lussen et al. 2005; Bult et al. 2007).

Food intake, however, is usually linked with swallowing—a process known to be triggered at least partially by gustatory stimulation (Sciortino et al. 2003). Considering that retronasal olfactory stimuli are associated with food intake and that gustatory stimuli contribute to the triggering of the complex swallow reflex, we examined whether retronasal and orthonasal olfactory food-like stimuli, in combination with a simultaneous congruent gustatory stimulus, differentially influence 1) the frequency of swallowing and 2) the latency of the first swallow after odorant perception.

Materials and methods

The study was conducted in accordance with the Declaration of Helsinki/Edinburgh after approval of the protocol by the

Ethics committee of the University of Basel. All subjects provided written informed consent.

Subjects

Out of 57 healthy volunteers screened, 50 nonsmoking subjects participated in the study. Data could be analyzed from 47 subjects (23 males and 24 females; mean age: 24.2 years; range: 18–42). Prior head trauma, nasal operation, and allergy were exclusion criteria. Olfactory function was ascertained using the "Sniffin' Sticks" screening test (Kobal et al. 1996). Gustatory function was screened by presentation of suprathreshold taste solutions (sweet, 10 g D-saccharose; sour, 5 g citric acid; salty, 7.5 g NaCl; and bitter, 0.05 g quinine sulfate, all dissolved in 100 ml water). All subjects included in the study were normosmic and normogeusic.

Rhinoscopic examination was performed to rule out major pathology and to check for nasal deviation. After spraying the decongestant xylometazolin (0.05%, 0.5 ml) in each nostril, the side of stimulation was chosen randomly. Due to septal deviations, stimulation was performed on the right side in 29 cases and on the left side in 18 cases.

Experimental conditions

All subjects took part in 1 experimental session, which lasted approximately 45 min. Ortho- and retronasal stimulation was performed via 2 intranasal Teflon tubes (4 and 8 cm in length; outer diameter, 4 mm; for details, see Heilmann and Hummel 2004). The tubes were inserted under endoscopic guidance so that 1 tube ended close to the external nares and the other ended close to the nasopharynx. After fixation of the tubes, subjects were seated comfortably and instructed that, when told, they must remove the olfactometer's outlet from one tubes' end and plug it into the other tubes' end. This measure changed ortho- to retronasal stimulation and vice versa. During the experiment, each subject had a taste dispenser placed in the vestibulum oris (space between teeth and cheek). Ultrasound examination of the mouth floor was started simultaneously with the start of the olfactory stimulation and recorded on videotape.

Olfactory stimulation

Olfactory stimulation was performed using a computer-controlled olfactometer (OM2s, Burghart instruments). Vanillin was used as the olfactory stimulus (30% v/v, total flow rate 7 l/min; temperature 36 °C; relative humidity >80%). The duration of the stimulus was 200 ms, and the interstimulus interval was 45 s. Altogether 16 stimuli were applied, 8 orthonasally and 8 retronasally. Stimulation order was randomized across the subjects. Olfactory stimuli were presented ortho- and retronasally via 2 Teflon tubes as explained above. Following each stimulus, subjects rated the perceived intensity on a visual analogue scale displayed on a computer screen. The left end of the scale was defined as "no stimulus perceived" (0 units), and the right end was defined as "extremely strong sensation" (100 units). Based on the randomization scheme, the investigator told the subjects when to change the outlet of the olfactometer to the different tubes (ortho- to retronasal and vice versa). Subjects knew that orthonasal was comparable to stimulation from outside the nose, whereas retronasal was comparable to stimulation during food consumption but were otherwise untrained concerning the localization of odorant stimulation. When asked to distinguish whether odorants were presented ortho- or retronasally, subjects performed no better than chance.

Gustatory stimulation

The taste dispenser (a plastic bag $4 \times 2 \times 1$ cm containing 6 holes of ca. 2–3 mm on each side) was filled with 7 g compressed glucose and due to its size remained in position inside the vestibulum oris during the experimental session. Sweet taste was perceived continuously during the session, as established in a previous study.

Recording of swallowing

Ultrasound recording of the mouth floor to document swallowing started simultaneously with the start of the olfactory stimulation. Ultrasound was performed using a Logiq 200 Pro (General Electric Healthcare, Medical Systems) using a 10.0-MHz sonar transducer. Throughout the experimental session, which lasted approximately 17 min, the ultrasound examination was recorded on videotape. The release of each stimulus was indicated by holding a forcep underneath the ultrasound transducer, thereby producing an artifact that could easily be identified on the video. The standard ultrasound formation recorded in a coronal plane was the typical "mouth floor picture" depicting Musculus digaster, Musculus mylohyoideus, and the tongue (consisting of Musculus genioglossus and Musculus geniohyoideus). This technique for recording swallowing has been described previously (Shawker et al. 1983, 1984; Ardakani 2006).

The videotapes of the ultrasound examination were evaluated by one of the authors (T.H.). Typical tongue movements during swallowing were counted 20 s after presentation of the odorous stimulus, and the latency of the swallows was noted. The examiner of the ultrasound videos was blinded concerning the site of stimulation (ortho- vs. retronasal).

Statistical analysis

Data were analyzed using SPSS 14 (SPSS Inc.) for Windows. *T*-tests for paired samples were employed wherever appropriate. In addition, chi-square tests were used. The alpha level was set at 0.05. All data are given as means ± standard errors of the means.

Results

As shown in Figure 1, orthonasal stimuli were rated as more intense (44.67 ± 2.6 estimation units [EU]) than retronasal stimuli (34.77 ± 2.7 EU) ($P < 0.001$).

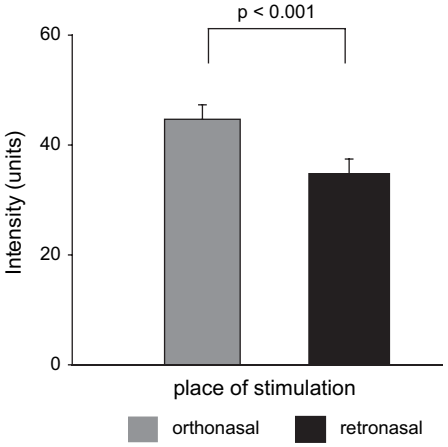

Figure 1 Intensity rating of ortho- and retronasal stimuli.

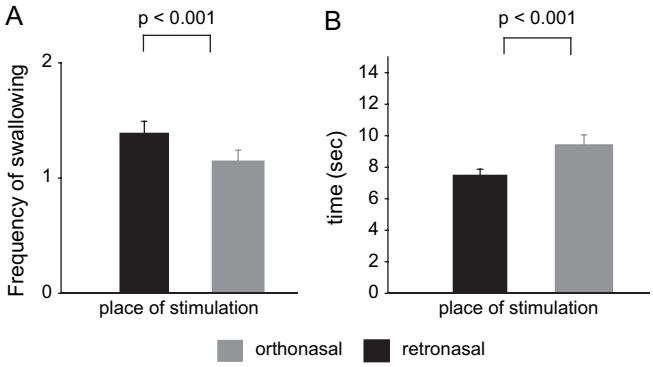

Figure 2 **(A)** Depicts the frequency of swallowing during the first 20 s after ortho- and retronasal olfactory stimulation. **(B)** Shows the time after olfactory stimulation (in seconds) at which the first swallow takes place.

During retronasal stimulation, subjects swallowed significantly more frequently (1.38 ± 0.1 times) than during orthonasal stimulation (1.14 ± 0.94 times; $P < 0.001$). Subjects also swallowed earlier during retronasal olfactory stimulation (7.49 ± 39 s after retronasal stimulation vs. 9.42 ± 0.63 s after orthonasal stimulation; $P < 0.001$). Results are shown in Figure 2A,B.

Discussion

The results of the present investigation suggest that retronasal olfactory stimulation using a food-like odorant, vanillin, in combination with a congruent sweet taste facilitates swallowing in terms of both the frequency of swallows and the latency of the first swallow following the odorous stimulus.

Swallowing is usually subdivided into 3 successive stages (as described more than 100 years ago by Magendie 1836): the oral, pharyngeal, and esophageal phases (Miller 1982). The oral phase is considered voluntary and highly variable in duration, depending on hunger, motivation, taste, and consciousness; however, the pharyngeal phase is considered a reflex response (Ertekin and Aydogdu 2003). The oral and pharyngeal phases have also been described as the ''oropharyngeal'' stage of swallowing, in contrast to the esophageal stage (Jean 2001). During food intake, mechanical pressing of the bolus toward the hard palate in the oropharyngeal phase and further movement toward the posterior part of the tongue eventually triggers the pharyngeal phase of swallowing. If no food is present, as in saliva swallowing, there is no oral preparation, and oral and pharyngeal stages occur sequentially (Ertekin and Aydogdu 2003). Once initiated, the pharyngeal phase of swallowing represents an irreversible motor event. This motor sequence involves not only pharyngeal and laryngeal muscles but also muscles in the oral cavity such as tongue and suprahyoid muscles (Jean 2001), thus constituting the rationale for use of ultrasound examination of the mouth floor to monitor swallowing.

The exact nature of the trigger of the pharyngeal phase in swallowing is not yet clearly known. Oral–pharyngeal reflexes demonstrate a range of complexity (Miller 2002), and it is very difficult to influence the swallowing reflex by a single modality alone (Pereira et al. 2008). In line with this complexity is the finding that a combination of a mechanical, a thermal (cold), and a gustatory (sour) trigger placed on the anterior faucial pillar resulted in significantly faster swallowing activity compared with that after each of the triggers alone (Sciortino et al. 2003). Thus, in our study, we chose a combination of 2 stimuli that might modulate one another, a gustatory and an olfactory stimulus, to influence swallowing activity instead of using one of these stimuli alone. Retronasal olfaction in particular is strongly associated with flavor and food consumption. This association has been demonstrated using fMRI in response to activation with orthonasal and retronasal presentation of chocolate odor (Small et al. 2005). Depending on the route of presentation, identical stimuli produce very different patterns of activation, clearly indicating that stimulus quality changes in relation to the mode of stimulation. In addition, compared with orthonasal stimuli, retronasal stimuli produce significantly stronger activation in an area that is known to be activated by oral mastication. On a behavioral level, it has been shown that retronasal, but not orthonasal, stimuli produce a significantly greater feeling of satiation (Ruijschop et al. 2008). In the present study, retronasal olfactory stimulation, but not orthonasal olfactory stimulation, accelerated swallowing activity in combination with gustatory stimuli. Interestingly, both gustatory nerves and the axons of nerves involved in initiating swallowing (the superior laryngeal branch) terminate in the nucleus tractus solitari (Miller 1972; Beckstead and Norgren 1979; Hamilton and Norgren 1984; Jean 2001; Rolls and Scott 2003). In addition to this convergence in the nucleus tractus solitari, certain cortical areas are involved in both swallowing (Hamdy et al. 1999; Mosier et al. 1999; Zald and Pardo 1999) and flavor processing (Small et al. 1999), as revealed by fMRI, namely, the insula,

the frontal operculum, and the anterior cingulate. Moreover, in retronasal olfactory stimulation, a region of the rolandic operculum at the base of the central sulcus has been identified (Small et al. 2005), corresponding to a primary representation of the oral cavity (Boling et al. 2002). With respect to these findings, taste perception and swallowing appear to interact with retronasal olfaction to a much greater extent than orthonasal olfaction. Thus, it can be assumed that the enhancement of the swallowing activity observed in the present study was due more to the route of presentation than to the quality of the odorant used, even though the use of only a single food-like odorant is a shortcoming of the present study, and further investigation to examine the influence of odor quality, hedonics, and familiarity on swallowing is required and planned. From the clinical point of view, these results can be used to improve swallowing training in patients with swallowing disorders. In these cases, training with odorized liquids should be recommended and might improve swallowing.

In summary, the results of the present study show that retronasal olfactory stimulation using a food-like odorant in combination with a gustatory stimulus influences swallowing, which is already known to be partially influenced by gustatory stimuli. Orthonasal stimulation does not exhibit such an influence. The ultimate mechanism responsible for this effect remains unknown. Moreover, it is not clear whether retronasal odors enhanced the effect of taste on swallowing or whether orthonasal stimulation decreased the influence of taste. The results, however, provide further support for the ''duality'' of the olfactory system (Rozin 1982), which allows for differential processing of ortho- and retronasal stimuli.

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