Published in final edited form as:

J Oral Rehabil. 2016 September ; 43(9): 662–669. doi:10.1111/joor.12419.

Effects of age and non-oropharyngeal proprioceptive and exteroceptive sensation on the magnitude of anticipatory mouth opening during eating

Samantha E. Shune^a and Jerald B. Moon^b

^aCommunication Disorders and Sciences, University of Oregon, Eugene, USA

^bDepartment of Communication Sciences and Disorders, University of Iowa, Iowa City, USA

Abstract

To best prevent and treat eating/swallowing problems, it is essential to understand how components of oral physiology contribute to the preservation and/or degradation of eating/swallowing in healthy aging. Anticipatory, pre-swallow motor movements may be critical to safe and efficient eating/swallowing, particularly for older adults. However, the nature of these responses is relatively unknown. This study compared the magnitude of anticipatory mouth opening during eating in healthy older (ages 70–85) and younger (ages 18–30) adults under four eating conditions: typical self-feeding, typical assisted feeding (being fed by a research assistant resulting in proprioceptive loss), sensory loss self-feeding (wearing blindfold/headphones resulting in exteroceptive loss), and sensory loss assisted feeding (proprioceptive and exteroceptive loss). Older adults opened their mouths wider than younger adults in anticipation of food intake under both typical and most non-oropharyngeal sensory loss conditions. Further, the loss of proprioceptive and exteroceptive cues resulted in decreased anticipatory mouth opening for all participants. Greater mouth opening in older adults may be a protective compensation, contributing to the preservation of function associated with healthy aging. Our finding that the loss of non-oropharyngeal sensory cues resulted in decreased anticipatory mouth opening highlights how important proprioception, vision, and hearing are in pre-swallow behavior. Age- and disease-related changes in vision, hearing, and the ability to self-feed may reduce the effectiveness of these pre-swallow strategies.

Keywords

Deglutition; Deglutition Disorders; Aged; Oropharynx; Eating; Motor Activity

Safe and effective swallowing requires the precise coordination and synchronization of oral, pharyngeal, laryngeal, and respiratory structures. Despite well-documented age-related changes in the swallowing mechanism (presbyphagia),^{1–4} healthy older adults frequently

Corresponding author: Dr. S. E. Shune, Communication Disorders and Sciences, 249 HEDCO Education Building, 5284 University of Oregon, Eugene, 97403, USA, sshune@uoregon.edu.

Disclosures

This study was reviewed and approved by the University of Iowa Institutional Review Board. All participants signed written informed consent prior to participation.

swallow safely. Yet, they are also more susceptible to swallowing problems (dysphagia).^{1, 2} Although chronic disease and acute illness can play a role, even otherwise healthy adults develop dysphagia. It is unclear what mechanisms may contribute to the preservation or degradation of safe, efficient swallowing in healthy aging.

Pre-movement, anticipatory muscle activity has been implicated in limb-related task completion and injury prevention, particularly for the elderly.⁵⁻⁷ Evidence suggests that motor programs can be modified in anticipation of motor execution based on sensory cues that are present prior to the movement itself.⁶ Increased gain and adaptation of feedforward controls in limb movement also contribute to injury prevention and task success.^{6, 7} Anticipatory, adaptive responses in muscle activation occurring prior to food delivery to the mouth for swallowing may be equally as important, but the nature of these responses, including the impact of pre-movement, non-oropharyngeal sensation on modifying these responses, is relatively unknown. We have previously found that both older and younger adults demonstrate generalized anticipatory mouth opening (i.e., movement prior to food reaching the mouth) given the presence of feeding-related proprioceptive and visual cues.⁸ Another study comparing “grasping to eat” and “grasping to place” in children showed that mylohyoid activation during eating begins prior to grasping food, indicating that the mouth opens in anticipation of oral intake.⁹

Clinically, the physiology of normal swallowing involves four main stages: oral preparatory, oral, pharyngeal, and esophageal.¹⁰ Yet, healthy eating also depends on a broad range of “pre-swallow,” or pre-oral, cognitive, motor, and sensory functions. These include increased alertness, auditory, olfactory, and visual cues to recognize food, and arm/hand coordination for food transport. Little is known about the factors that comprise this pre-oral stage. Specifically addressing non-oropharyngeal sensation, two sensory ‘classes’ particularly relevant to eating and swallowing are exteroception and proprioception.¹¹ Exteroceptive senses provide the nervous system with information about the external world, or cues from outside the body, including eating-related auditory, olfactory, and visual cues. Proprioceptive senses provide the nervous system with information and awareness about the body itself, or cues from inside the body, including hand/arm proprioception during self-feeding. Our previous work has suggested that different types of non-oropharyngeal sensory cues differentially influence anticipatory mouth opening, with proprioception appearing to be essential for timing onset of mouth opening and exteroception (primarily vision) crucial for movement offset.⁸ Drawing on limb-related literature⁵⁻⁷ and research on sensorimotor integration in swallowing,¹²⁻¹⁶ it is expected that these non-oropharyngeal sensory cues as part of the overall pre-oral stage are essential to the initiation and modulation of the four later stages. While a bolus is prepared for the swallow during the oral preparatory stage, the sensorimotor system itself may prepare for the swallow during the pre-oral stage, playing a critical role in swallow safety. This relationship may be even more essential for safety given advanced age and given the age-related changes present elsewhere in the swallow system (i.e., presbyphagia).

One of the earliest components of the swallow sequence that begins during the pre-oral preparatory stage and can impact overall swallow efficiency is mouth opening. Mouth opening is necessary to ready the mouth for bolus acceptance and ultimate bolus extraction

(e.g., from a spoon/cup). For example, if the oral structures are not prepared for bolus acceptance and extraction (e.g., food/drink arrives too early to the oral cavity, the mouth is not open wide enough), the mouth may not be primed to initiate bolus preparation leading to a loss of bolus control (e.g., anterior loss of bolus, premature spillover into the pharyngeal cavity). Thus, anticipatory mouth opening during the pre-oral stage is a critical component of safe and efficient eating and swallowing. Of interest, in our previous work older adults initiated anticipatory mouth opening significantly earlier than younger adults.⁸ This earlier movement may signal a compensatory strategy used by older adults for maintaining swallow safety in the presence of presbyphagia. For example, older adults may begin mouth-opening movements earlier to compensate for greater lowering prior to food consumption. A larger lowering gesture may result from various sensorimotor changes associated with eating/swallowing. Older adults may need greater sensory feedback to determine that an optimal mouth position has been achieved or may need a wider “target” (i.e., mouth opening) to reduce potential burden associated with a need for increased hand/arm precision. However, limited research on such movement exists and there is no research evidence that defines the relationship between the magnitude of anticipatory mouth opening, the presence of non-oropharyngeal sensation, and aging.

Thus, the purpose of the current study was to compare anticipatory mouth opening (i.e., lower lip displacement) during eating in older and younger adults under various sensory conditions (i.e., presence/absence of non-oropharyngeal exteroceptive and proprioceptive cues). Based on our previous work, it was hypothesized that older adults would demonstrate greater lip displacement given the presence of at least one non-oropharyngeal sensory cue. We also hypothesized that irrespective of age, sensory condition would also impact overall displacement with magnitude of lip displacement decreasing given increased quantity of sensory cues lost.

Methods

Participants

Participants ($n = 48$) were self-rated healthy, community dwelling adults, including 24 younger adults ($M_{\text{age}} = 24.4$ years, $SD = 2.5$; 12 females) and 24 older adults ($M_{\text{age}} = 76.1$ years, $SD = 4.5$; 12 females). All participants had normal or corrected vision and hearing, normal oral motor, vestibular, and upper extremity function, normal oral, facial, and upper extremity sensation, a Mini-Mental State Examination score ≥ 26 , and a negative history of confounding medical, neurological, or musculoskeletal disease or disorder and medication use that could influence neurologic and/or motor function.

Task procedures

The current study was one component of a larger experiment and a more detailed description of the task procedures and data collection methods are reported elsewhere.⁸ The Institutional Review Board at the participating institution approved all task procedures. Briefly, participants consumed one teaspoon of applesauce via spoon under four different experimental conditions. Conditions varied based on available proprioceptive (presence/“self-feeding” versus absence/“assisted feeding”) and exteroceptive (presence/“typical”

versus absence/“sensory loss”) cues. Thus, the four conditions were: “typical self-feeding”, “typical assisted feeding”, “sensory loss self-feeding”, and “sensory loss assisted feeding”. During assisted feeding conditions, a research assistant fed participants, thereby removing proprioceptive cues. During sensory loss conditions, participants were blindfolded and wore sound attenuating headphones, thereby removing visual and attenuating auditory cues. A total of 10 trials of the pureed stimulus were presented in each condition. Two different cues were utilized at trial onset to indicate that feeding should begin. During the self-feeding conditions, participants heard an audio cue. During the assisted feeding conditions, the research assistant received a visual cue (i.e., no auditory cue was provided to the participant that feeding would begin). Participants were instructed to consume the presented material completely and as naturally as possible. No other instructions, including any related to speed of hand/arm movement or timing of mouth opening, were provided.

Data collection and analysis

Hand/arm (participant during self-feeding, research assistant during assisted feeding), lower lip, and lip/jaw complex movement during eating were sensed using the Optotrak Certus motion detection system (Northern Digital, Waterloo, Canada). Small infrared-emitting diodes were placed midline on the forehead (reference point), lower lip, and chin of each participant, and on the index finger of the dominant hand of the participants during self-feeding and the research assistant during assisted feeding. From the movement data, three primary measures were taken and/or calculated: lower lip position at baseline/onset of feeding (prior to anticipatory mouth opening), lower lip position at maximal lowering (prior to closing the mouth for bolus extraction), and total anticipatory lip lowering displacement (i.e., difference between baseline and maximal measurements). The baseline and peak positions were measured relative to a reference point on the forehead to account for head motion. As lower lip movement effectively captured the combined movement of the lower lip/jaw complex and as the measures of interest related primarily to lip/jaw lowering for mouth opening (versus, for example, lip puckering), lower lip movement in the vertical direction was targeted. A sample x-dimension lower lip tracing is presented in Figure 1; the first and second arrows indicate lip position at baseline and at maximal lowering relative to the forehead referent, respectively. While contact between the spoon and lip (i.e., the onset of oropharyngeal sensation) may have occurred prior to maximal lowering, our previous work has shown that the majority of lip lowering movement for mouth opening occurs prior to such contact and thus the entire length of lip lowering displacement here is referred to as “anticipatory mouth opening” (i.e., opening prior to bolus extraction for oral preparation).

Statistical analysis

Three dependent variables were analyzed: lower lip position at baseline (LLbase), lower lip position at maximal lowering (LLmax), and total anticipatory lip lowering displacement (LLdis). Means were calculated within each participant (across the 10 trials) and for each age group. Independent sample t-tests were used to quantify differences in means between the two age groups under typical eating conditions. A p -value of $< .05$ was considered statistically significant. Three-way mixed ANOVAs were used to test the effects of and interactions between group membership (i.e., older versus younger), proprioception (i.e., self versus assisted), and exteroception (i.e., typical versus sensory loss) on the dependent

variables. A Bonferroni adjustment for multiple comparisons was used for the post-hoc tests of the simple effects. Statistical analysis was performed using SPSS (IBM Corporation, Armonk, NY).

Results

Age-related differences during typical eating conditions

Table 1 presents summary data for LLbase, LLmax, and LLdis for older and younger adults during the typical eating condition. Older adults demonstrated greater total anticipatory lip lowering displacement than younger adults ($t(46) = 1.964, p = .028$, Cohen's $d = 0.568$) resulting from a greater maximal lowering position ($t(46) = 2.412, p = .010$, Cohen's $d = 0.698$). Lower lip position at baseline did not differ between groups ($t(46) = 1.700, p = .096$).

Sensory-related differences across eating conditions

Figures 2–4 present lower lip positions at baseline and maximal lowering and total anticipatory lip displacements for older and younger adults across the four experimental conditions. In the model generated for *lower lip position at baseline*, main effects for proprioception ($F(1,46) = 7.799, p = .008$) and exteroception ($F(1,46) = 8.067, p = .007$) and the interaction between proprioception and group ($F(1,46) = 5.022, p = .030$) were statistically significant. The interaction between exteroception and group approached significance ($F(1,46) = 4.025, p = .051$). Overall, lower lip position at baseline was lower (i.e., further from the forehead reference point) during assisted feeding than self-feeding and given exteroceptive loss versus typical exteroceptive cues (Figure 2). Close inspection, however, revealed that these differences were primarily driven by the younger adults, especially in the assisted feeding exteroceptive loss condition. The older adults demonstrated limited to no difference in baseline placement across the four conditions.

In the model generated for *lower lip position at maximal lowering*, main effects for group ($F(1,46) = 4.442, p = .041$), proprioception ($F(1,46) = 24.974, p < .001$), and exteroception ($F(1,46) = 65.932, p < .001$) and the interaction between proprioception and exteroception ($F(1,46) = 24.112, p < .001$) were statistically significant. The interaction between exteroception and group approached significance ($F(1,46) = 3.796, p = .057$). Lower lip position at maximal lowering was more inferior for older adults than younger adults, during self-feeding versus assisted feeding, and given typical exteroceptive cues versus exteroceptive loss (Figure 3). The influence of proprioception was greater given exteroceptive loss than when typical exteroceptive cues were available and exteroceptive loss effects were greater during assisted feeding than when self-feeding. Exteroceptive loss tended to more greatly impact movement in older adults, however this interaction was not statistically significant.

In the model generated for *total lower lip displacement*, main effects for group ($F(1,46) = 7.609, p = .008$), proprioception ($F(1,46) = 36.330, p < .001$), and exteroception ($F(1,46) = 143.675, p < .001$) and the interaction between proprioception and exteroception ($F(1,46) = 18.440, p < .001$) were statistically significant. Total lower lip displacement was greater for

older adults than younger adults, during self-feeding versus assisted feeding, and given typical exteroceptive cues as compared to exteroceptive loss (Figure 4). Similar to LLmax, the influence of proprioception was greater given exteroceptive loss than when typical cues were available and exteroceptive loss effects were greater during assisted feeding than when self-feeding.

Conclusions and Discussion

To best prevent and treat eating and swallowing problems across clinical populations, it is essential to understand how components of oral physiology contribute to the preservation or degradation of safe and efficient eating and swallowing in healthy aging. This study was designed to examine the magnitude of anticipatory mouth opening during eating and the influence of age and non-oropharyngeal proprioceptive and exteroceptive sensory cues on this movement. Older adults opened their mouths wider in anticipation of food intake under both typical and most non-oropharyngeal sensory loss conditions. For all participants, the loss of sensory cues resulted in decreased anticipatory mouth opening as compared to the typical condition.

The finding that older adults exhibited greater anticipatory mouth opening than younger adults is consistent with our previous findings of earlier mouth opening initiation in older adults.⁸ In other words, it is likely that older adults begin mouth opening in anticipation of eating earlier to compensate for greater magnitude of opening prior to bolus extraction. It was previously suggested that a larger opening gesture reflects a need for greater feedback to determine that an optimal mouth position has been achieved. For example, in order to identify an appropriately lowered lip/jaw position for bolus acceptance, older adults may require greater tension on the jaw mechanoreceptors as compared to younger adults. In support, older adults do exhibit increased sensory discrimination thresholds in the oral cavity and pharynx and increased muscle activity during mastication.^{17–20} Older adults also demonstrate slower, more variable upper limb movements that stem from proprioceptive declines during skilled movement.²¹ Thus, a larger mouth opening gesture could also create a wider “target” for the cup/spoon, reducing potential burden associated with need for increased hand/arm precision. Such compensatory strategies suggest that synergistic-like motor patterns exist during the pre-oral stage of swallowing, allowing structures to re-adjust given, for example, an imposed constraint or age-related physiologic change (presbyphagia), in order to maintain the necessary coordination of task completion.²² This dynamic ability of the central nervous system to tailor coordinative motor actions to best meet changing task demands, as previously demonstrated during the oropharyngeal stages of swallowing,^{23–25} is expected to be a strong contributor to overall system efficiency and safety.

It is of interest to note that the larger mouth opening gesture was associated with *earlier onset* of movement in older adults rather than later offset. Older adults appear to capitalize on the availability of non-oropharyngeal sensory cues (e.g., proprioception, exteroception) to modify their motor behaviors, compensating for age-related changes in the swallowing system (i.e., presbyphagia) and elsewhere (e.g., upper limb movement variability). It is plausible that older adults compensate for such changes by increasing their reliance on anticipatory movements, providing increased time for the system to ready itself prior to

actual food/drink delivery, similar to previous suggestions regarding limb-related injury prevention.^{5–7} This could serve as a critical protective mechanism for continued safety and efficiency during eating. Thus, older adults may begin the mouth opening gesture earlier so that their maximal mouth opening position, which is greater than younger adults, can be achieved at the same time as their younger adult counterparts. This timing is critical for swallow efficiency when moving from one swallow stage (i.e., pre-oral) to the next (i.e., oral preparatory) and may additionally be critical for safety (e.g., food not arriving before the correct oral posture is achieved). Older adults demonstrate a delay in the initiation of the pharyngeal response and increased variability in the timing of and transition between the oropharyngeal stages.^{1, 2, 26} It is also known that older adults require a larger volume of water to trigger the pharyngoglottal closure reflex, which adducts the vocal folds given entry of any material into the pharynx.²⁷ Despite these changes, kinematic properties of the bolus – such as the speed with which it can travel through the oropharyngeal system – remain unchanged. This would suggest an increased risk of airway compromise among older adults, particularly as related to premature spillover. However, an increased incidence of aspiration is not necessarily observed among healthy older adults.^{2, 4} We expect that an increased magnitude of and reliance on anticipatory mouth opening and the pre-oral stage of swallowing contribute to these findings. This hypothesis requires further exploration.

Atypical sensory conditions differentially impacted the magnitude of anticipatory mouth opening. In general, all participants demonstrated a larger mouth opening gesture when self-feeding than when being fed and given typical exteroceptive cues as compared to given the loss of such cues. The impact of the loss of both proprioception and exteroception was greater than the impact of one loss alone, resulting in smaller anticipatory mouth opening for all participants. Further, the older adults' potential protective compensation of greater mouth opening appeared to be eliminated when all non-oropharyngeal sensory cues were decreased/diminished. Thus, while the loss of non-oropharyngeal sensory cues decreased mouth opening (maximal lowering and total displacement) in all healthy adults, the clinical impact may be more severe among older adults.

It remains unclear what the clinical ramifications and significance of decreased anticipatory mouth opening are, one limitation of the present investigation. In the current study of healthy adults, we did not observe any overt signs of eating or swallowing difficulty that could be attributable to decreased anticipatory, or preparatory, movement (e.g., anterior loss of bolus, premature spillover with potential aspiration). However, given concomitant dysphagia or disease or increased task demands (e.g., larger, more rapid bites/sips), such risks may become more prevalent. Further, it is not known what this anticipatory movement looks like in non-healthy individuals. If greater mouth opening in older adults is indeed a protective compensation, contributing to the preservation of safe, efficient swallowing in healthy aging, it is plausible that the degradation of swallowing, or dysphagia, results from deficient or inadequate anticipatory mouth movement. Thus, such a deficit may not only interact with dysphagia, but could potentially have a causal relationship to some aspects of dysphagia, implicating new treatment targets. This relationship warrants further investigation.

In understanding the contribution of non-oropharyngeal sensation to these anticipatory movements across the lifespan, it is worth noting that while the loss of these cues can certainly be attributable to the aging process (e.g., negative changes in hearing, vision, and olfactory thresholds;^{18, 28} proprioceptive declines in the upper limbs²¹), loss of cues can occur in association with other naturally occurring conditions. For example, an individual with attention or cognitive impairments who also requires feeding assistance may not be aware of the onset of feeding (e.g., not visually notice a hand moving towards him/her for feeding, not hear an auditory prompt for feeding). This would also create a situation of proprioceptive and exteroceptive loss.

While the current study was limited to anticipatory mouth opening, it is expected that movement of additional oral structures and other swallow-related actions begin during this pre-oral stage. Variations in lingual movement and coordination, important components of swallow efficiency and safety, occur during mastication, bolus preparation, and oral transit.²⁴ The onset of respiratory inhibition has also been found to occur in some adults prior to the onset of oral sensation,²⁹ with eating-related respiratory patterns demonstrating careful organization during this time.³⁰ Thus, while our findings suggest that anticipatory mouth opening and the age-related changes that occur in the magnitude and timing of this gesture contribute to the preservation of safe, efficient swallowing with advancing age, other eating-related anticipatory movements (e.g., lingual and respiratory actions) likely also contribute. It is necessary to investigate these actions further.

The pre-oral stage of swallowing, during which the sensorimotor system can prepare itself for the swallow sequence, likely plays a critical role in swallow efficiency and safety. These anticipatory mouth movements are thus important to consider, particularly given advanced age when age-related changes and deteriorations are present in the swallow system and elsewhere. Further investigation into the presence and role of anticipatory swallowing movements will continue to offer insight into the mechanisms that contribute to the preservation or degradation of safe, efficient swallowing in healthy aging. This will ultimately advance not only our theoretical understanding of the relationship between aging, sensorimotor control, and swallowing, but can further advance clinical practice toward focusing on risk prevention and optimization of function, particularly for older adults.

Acknowledgments

The authors report grants during the conduct of the study. This work was supported by grants from the National Institute on Aging at the National Institutes of Health (F31AG042255) and the University of Iowa Executive Council of Graduate and Professional Students (awarded to S. Shune).

We thank M. Cook for her assistance in data collection and S. Goodman for his programming assistance.

References

1. Ney DM, Weiss JM, Kind AJ, Robbins J. Senescent swallowing: impact, strategies, and interventions. *Nutr Clin Pract*. 2009; 24(3):395–413. [PubMed: 19483069]
2. Robbins J, Hamilton JW, Lof GL, Kempster GB. Oropharyngeal swallowing in normal adults of different ages. *Gastroenterology*. 1992; 103(3):823–9. [PubMed: 1499933]
3. Humbert IA, Robbins J. Dysphagia in the elderly. *Phys Med Rehabil Clin N Am*. 2008; 19(4):853–66. ix–x. [PubMed: 18940645]

4. Logemann JA, Pauloski BR, Rademaker AW, Colangelo LA, Kahrilas PJ, Smith CH. Temporal and biomechanical characteristics of oropharyngeal swallow in younger and older men. *J Speech Lang Hear Res.* 2000; 43(5):1264–74. [PubMed: 11063246]
5. Fogassi L, Ferrari PF, Gesierich B, Rozzi S, Chersi F, Rizzolatti G. Parietal lobe: from action organization to intention understanding. *Science.* 2005; 308(5722):662–7. [PubMed: 15860620]
6. Johansson RS, Westling G. Programmed and triggered actions to rapid load changes during precision grip. *Exp Brain Res.* 1988; 71(1):72–86. [PubMed: 3416959]
7. Besier TF, Lloyd DG, Ackland TR, Cochrane JL. Anticipatory effects on knee joint loading during running and cutting maneuvers. *Medicine and Science in Sports Education.* 2001; 33(7):1176–81.
8. Shune S, Moon JB, Goodman SS. The effects of age and pre-oral sensorimotor cues on anticipatory mouth movement during swallowing. *J Speech Lang Hear Res.* 2016; 59:195–205. [PubMed: 26540553]
9. Cattaneo L, Fabbri-Destro M, Boria S, Pieraccini C, Monti A, Cossu G, et al. Impairment of actions chains in autism and its possible role in intention understanding. *Proc Natl Acad Sci U S A.* 2007; 104(45):17825–30. [PubMed: 17965234]
10. Logemann, JA. Evaluation and treatment of swallowing disorders. Austin, TX: PRO-ED; 1998.
11. Sherrington, CS. The integrative action of the nervous system. New Haven, CT: Yale University Press; 1906.
12. Steele CM, Miller AJ. Sensory input pathways and mechanisms in swallowing: a review. *Dysphagia.* 2010; 25(4):323–33. [PubMed: 20814803]
13. Ding R, Logemann JA, Larson CR, Rademaker AW. The effects of taste and consistency on swallow physiology in younger and older healthy individuals: A surface electromyographic study. *J Speech Lang Hear Res.* 2003; 46(4):977–89. [PubMed: 12959474]
14. Hiraoka K. Fixation of the mandible changes masseter muscle activity associated with swallowing. *Int J Neurosci.* 2004; 114(8):947–57. [PubMed: 15527201]
15. Martin RE, Murray GM, Kemppainen P, Masuda Y, Sessle BJ. Functional properties of neurons in the primate tongue primary motor cortex during swallowing. *J Neurophysiol.* 1997; 78(3):1516–30. [PubMed: 9310440]
16. Steele CM, Van Lieshout PH. Influence of bolus consistency on lingual behaviors in sequential swallowing. *Dysphagia.* 2004; 19(3):192–206. [PubMed: 15383949]
17. Aviv JE. Effects of aging on sensitivity of the pharyngeal and supraglottic areas. *The American Journal of Medicine.* 1997; 103(5):74S–6S. [PubMed: 9422628]
18. Chavez E, Ship J. Sensory and motor deficits in the elderly: Impact on oral health. *J Public Health Dent.* 2000; 60(4):297–303. [PubMed: 11243050]
19. Peyron M, Blanc O, Lund J, Woda A. Influence of age on adaptability of human mastication. *J Neurophysiol.* 2004; 92(2):773–9. [PubMed: 15277595]
20. Rastatter MP, McGuire RA, Bushong L, Loposky M. Speech-motor equivalence in aging subjects. *Percept Mot Skills.* 1987; 64(2):635–8. [PubMed: 3588206]
21. Adamo DE, Martin BJ, Brown SH. Age-related differences in upper limb proprioceptive acuity. *Percept Mot Skills.* 2007; 104:1297–309. [PubMed: 17879664]
22. Kelso JS, Tuller B, Vatikiotis-Bateson E, Fowler CA. Functionally specific articulatory cooperation following jaw perturbations during speech: evidence for coordinative structures. *J Exp Psychol Hum Percept Perform.* 1984; 10(6):812–32. [PubMed: 6239907]
23. Hattori Y, Shimizu Y, Satoh C, Watanabe M. Masticatory Motion Is Controlled in Humans by a Limited Set of Muscle Synergies. *The Tohoku Journal of Experimental Medicine.* 2010; 220(3): 217–22. [PubMed: 20208417]
24. Steele CM, Van Lieshout PH. The dynamics of lingual-mandibular coordination during liquid swallowing. *Dysphagia.* 2008; 23(1):33–46. [PubMed: 17701249]
25. Moore CA, Smith A, Ringel RL. Task-specific organization of activity in human jaw muscles. *J Speech Hear Res.* 1988; 31:670–80. [PubMed: 3230897]
26. Robbins J, Coyle J, Rosenbek J, Roecker E, Wood J. Differentiation of normal and abnormal airway protection during swallowing using the Penetration-Aspiration Scale. *Dysphagia.* 1999; 14:228–32. [PubMed: 10467048]

27. Shaker R, Ren J, Bardan E, Easterling C, Dua K, Xie P, et al. Pharyngoglottal closure reflex: characterization in healthy young, elderly and dysphagic patients with predeglutitive aspiration. *Gerontology*. 2003; 49(1):12–20. [PubMed: 12457045]
28. Elsner RJF. Changes in eating behavior during the aging process. *Eating Behaviors*. 2002; 3:15–43. [PubMed: 15001018]
29. Martin-Harris B, Brodsky MB, Michel Y, Ford CL, Walters B, Heffner J. Breathing and swallowing dynamics across the adult lifespan. *Archives of Otolaryngology--Head & Neck Surgery*. 2005; 131(9):762–70. [PubMed: 16172351]
30. Selley WG, Flack FC, Ellis RE, Brooks WA. The Exeter dysphagia assessment technique. *Dysphagia*. 1990; 4(4):227–35. [PubMed: 2209098]

Figure 1.

A sample movement waveform in the x-dimension (vertical movement) for the lower lip sensor across time relative to the reference point (forehead sensor) during typical self-feeding. The approximate baseline and maximal lip lowering values are indicated by the first and second arrows, respectively.

Figure 2. Lower lip position at baseline for older and younger adults across four experimental conditions. *Note:* *SL* = sensory loss. Error bars indicate the 90th and 10th percentiles. All data points outside this range are marked as outliers (shaded circles).

Figure 3. Lower lip position at maximal lowering for older and younger adults across four experimental conditions. *Note:* SL = sensory loss. Error bars indicate the 90th and 10th percentiles. All data points outside this range are marked as outliers (shaded circles).

Figure 4. Total anticipatory lower lip displacement for older and younger adults across four experimental conditions. *Note:* SL = sensory loss. Error bars indicate the 90th and 10th percentiles. All data points outside this range are marked as outliers (shaded circles).

Table 1

Anticipatory lower lip position and displacement for older and younger adults during typical eating.

	Older Adults	Younger Adults
LLbase (mm)	132.53 (8.90)	127.72 (10.64)
LLmax (mm)	161.75 (9.54)	154.42 (11.38)
LLdis (mm)	29.20 (5.05)	26.67 (3.77)

Note: LLbase = lower lip position at baseline; LLdis = total anticipatory lip lowering displacement; LLmax = lower lip position at maximal lowering; mm = millimeters. Values are mean (standard deviation).