Research Article

The Effects of Age and Preoral Sensorimotor Cues on Anticipatory Mouth Movement During Swallowing

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Purpose: The aim of this study was to investigate the effects of preoral sensorimotor cues on anticipatory swallowing/eating-related mouth movements in older and younger adults. It was hypothesized that these cues are essential to timing anticipatory oral motor patterns, and these movements are delayed in older as compared with younger adults.

Method: Using a 2 × 2 repeated-measures design, eating-related lip, jaw, and hand movements were recorded from 24 healthy older (ages 70–85 years) and 24 healthy younger (ages 18–30 years) adults under 4 conditions: typical self-feeding, typical assisted feeding (proprioceptive loss), sensory-loss self-feeding (auditory and visual loss/degradation), and sensory-loss assisted feeding (loss/degradation of all cues).

Results: All participants demonstrated anticipatory mouth opening. The absence of proprioception delayed lip-lowering onset, and sensory loss more negatively affected offset. Given at least 1 preoral sensorimotor cue, older adults initiated movement earlier than younger adults.

Conclusions: Preoral sensorimotor information influences anticipatory swallowing/eating-related mouth movements, highlighting the importance of these cues. Earlier movement in older adults may be a compensation, facilitating safe swallowing given other age-related declines. Further research is needed to determine if the negative impact of cue removal may be further exacerbated in a nonhealthy system (e.g., presence of dysphagia or disease), potentially increasing swallowing- and eating-related risks.

As the prevalence of age-related diseases continues to increase, the number of patients with swallowing problems (dysphagia) and complex health care needs will also increase (Ney, Weiss, Kind, & Robbins, 2009; U.S. Department of Health and Human Services, 2014). Dysphagia and its often-associated sequelae, including pneumonia, malnutrition, and dehydration, are common, potentially life-threatening conditions suffered by many older individuals. Dysphagia is estimated to occur in up to 20%–40% of individuals over the age of 50–60 years with prevalence as high as 80% in patients with a variety of health conditions, including age-related diseases, such as stroke and dementia (Cabre et al., 2014; Howden, 2004; Martino et al., 2005; Ney et al., 2009; Roy, Stemple, Merrill, & Thomas, 2007; Siebens et al., 1986). Given its broad biopsychosocial ramifications, dysphagia is likely a strong contributor to the high physical, psychosocial, and financial

costs associated with disease (Altman, Yu, & Schaefer, 2010; Ney et al., 2009; Nguyen et al., 2005). The yearly economic impact of dysphagia in hospitalization alone exceeds \$547 billion (Altman et al., 2010).

Further, the cognitive, physical, and sensory impairments often seen in individuals with dementia and following stroke frequently result in eating needs going unmet, leading to increased morbidity and premature mortality (Amella, 2004; Chang & Roberts, 2008; Lin, Watson, & Wu, 2010). The functional limitations of many of these adults necessitate extensive feeding assistance, a strategy thought to decrease risks during eating; data suggest that nearly 50% of residents in skilled nursing facilities require such assistance (Amella, 2004; Dey, 1997; Edahiro et al., 2012; Siebens et al., 1986). Yet, feeding assistance fundamentally alters the eating process, often removing typical anticipatory sensorimotor cues, such as proprioception and vision, which are available prior to the swallow. Thus, feeding assistance creates a large subset of individuals who experience oropharyngeal sensorimotor loss, which results in dysphagia, and absent or incorrect eating-related anticipatory sensorimotor cues. Eating dependency is correlated with higher mortality and is a dominant risk factor for aspiration pneumonia, yet the underlying mechanism driving these negative outcomes is

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unclear (Langmore et al., 1998; Siebens et al., 1986). Of clinical importance, the task of mealtime support is also often assigned to lesser trained staff, who may be unaware of the importance of, and often do not adhere to, issues such as pacing, positioning, and bolus size (Aziz & Campbell-Taylor, 1999; Chadwick, Jolliffe, & Goldbart, 2003). Thus, despite intent to promote mealtime safety, assisted feeding may actually decrease swallow safety for older adults, particularly when paired with dysphagia. The intention of this study was to specifically investigate the effects of these anticipatory, preoral sensorimotor cues on swallowing/eating-related mouth movements in older and younger adults.

Especially within the clinical realm, the physiology of normal swallowing traditionally involves consideration of four main stages of the swallow: the oral preparatory, oral, pharyngeal, and esophageal phases (Logemann, 1998). Together, these phases track the bolus from oral preparation (or manipulation) to its transit from the oropharyngeal cavities and into the stomach through the esophagus. Although temporally linked and occurring in sequence, some variation may be observed as a function of age, particularly as related to the timing of swallowing movements and changes in sensitivity (e.g., older adults demonstrate a prolonged oropharyngeal phase, a delay in switching from the oral to the pharyngeal phase, and a delay in the initiation of the pharyngeal response as compared with younger adults; Logemann et al., 2000; Mendell & Logemann, 2007; Robbins, Hamilton, Lof, & Kempster, 1992). It is unfortunate that limited attention has been placed on the factors comprising a preoral, or supramedullary, stage of swallowing that may influence behavior in later swallow stages. Mastication arguably begins when foods and/or liquids meant for consumption are recognized as such during this preoral or anticipatory stage of swallowing; the thoughts, actions, and intents necessary to ingest these foods and liquids are an integral part of overall eating behavior (Elsner, 2002; Leopold & Kagel, 1983, 1997; Logemann, 1998; Maeda et al., 2004; Siebens et al., 1986). Such individual- and environmental-level factors important to the eating and feeding processes include audition (e.g., hearing sounds associated with the food/liquid to be ingested), cognition (e.g., alertness, anticipation, awareness, and motivation), olfaction (e.g., smelling the food/liquid to be ingested), proprioception (e.g., associated with reaching for and grasping the food/liquid to be ingested), and vision (e.g., seeing the food/liquid to be ingested). It is clear that the process of eating, as a whole, not only involves the act of swallowing as traditionally described above. Rather, this process also involves the behavioral and cognitive abilities to recognize food and the transfer of food to the mouth—all antecedents to the oropharyngeal swallow itself (Siebens et al., 1986).

Premovement, anticipatory muscle activity has been implicated in limb-related task completion and injury prevention, particularly in the older population (Besier, Lloyd, Ackland, & Cochrane, 2001; Fogassi et al., 2005; Johansson & Westling, 1988). For example, during precision grip tasks, preparatory actions in the hand/arm muscles have been

shown to be modifiable on the basis of pretask sensory information and task-specific goals to ensure success (e.g., Johansson & Westling, 1988). These findings also point to the notion of a central set or the tuning of gain of the central nervous system in anticipation of movement; such tuning can be one contributor to injury prevention. Instruction, expectation, motivation, and prior experience can all modify the central set and ultimately influence the movement response (Besier et al., 2001; Johansson & Westling, 1988).

However, the translation of such findings to swallowing is limited. The threshold for swallowing is affected by stimuli that induce increased salivation, which include auditory, olfactory, and visual cues in addition to more direct sensory cues within the oropharyngeal cavity (Ebihara et al., 2006; Maeda et al., 2004; Steele & Miller, 2010). In addition to salivation, anticipation of a meal is a sufficient stimulus to activate motor nuclei involved in ingestion and digestion (Emond & Weingarten, 1995). Further, the onset of mouth opening and respiratory cessation for swallowing have been observed to occur in some individuals even prior to the onset of oral sensation (Cattaneo et al., 2007; Martin-Harris et al., 2005) and thus may be attributable to more preoral stage events.

It is essential to determine if disruptions in sensory feedback during the preoral stage of swallowing affect the pattern and timing of later swallowing as these alterations in the temporal and coordinative aspects of the swallow may predispose even a healthy individual to an increased risk of aspiration or other negative events. Yet the effects of preoral sensorimotor cues on eating and swallowing safety in healthy systems and the potential increased risk of absent cues are unknown. To be specific, it is unclear how the processing of sensory information that is available prior to swallowing affects and interacts with the movement responses involved in swallowing itself. Two sensory “classes” particularly relevant to the eating and swallowing processes are exteroception and proprioception (Sherrington, 1906). Exteroceptive sensation (i.e., audition, gustation, olfaction, somatosensation/touch, vision) provides information about the external world, allowing the brain to interpret cues that come from outside the body, and proprioceptive sensation (e.g., of the hand/arm during feeding) provides awareness of the body itself, allowing the brain to interpret the body’s interaction with the environment through internal cues. The relative contribution and importance of each type of cue to eating and swallowing, including the ability for one form of feedback to adequately compensate for the loss of another, is additionally unknown.

The purpose of this study was to investigate how preoral, or nonoropharyngeal, exteroceptive and proprioceptive cues (termed *sensorimotor cues* to emphasize the relationship between these sensory system inputs and swallowing-related motor output) affect anticipatory motor patterns involving the hand/arm and lip/jaw complex under typical and sensory-loss conditions in healthy older and younger adults. We hypothesized that anticipatory mouth movements would occur given available preoral sensorimotor cues; however, these movements would be delayed in older

adults as compared with younger adults and given cue degradation.

Method

Participants

Forty-eight self-rated healthy adults participated in this study: 24 younger adults (18–30 years old, $M = 24.4$, $SD = 3.5$) and 24 older adults (70–85 years old, $M = 76.1$, $SD = 4.5$). Sex (12 women and 12 men per group) and handedness (22 younger right-handed participants; 20 older right-handed participants) were closely balanced between groups. Inclusion criteria included normal or corrected vision and hearing; normal upper extremity range of motion, balance, and vestibular function; and a negative history of confounding disease, disorder, or medication use that may influence neurologic and/or motor function. Screenings of cognition (Mini-Mental State Examination; Folstein, Folstein, & McHugh, 1975) and oral and upper extremity sensorimotor function were completed to ensure that all were within functional limits. The local institutional review board approved the study. All participants signed written informed consent prior to participation.

Task Procedures

Participants were briefed on all procedures prior to initiation. Each testing session contained four experimental conditions: typical self-feeding, typical assisted feeding, sensory-loss self-feeding, and sensory-loss assisted feeding. A two-by-two design was used in developing the conditions; that is, experimental conditions varied on the basis of feeding dependency (self-feeding vs. assisted feeding) and sensory loss (presence/typical vs. absence/sensory loss). The order of condition presentation was randomized for each participant. During each condition, participants were presented with 10 teaspoon-sized bites of applesauce. Small sips of water were also presented randomly throughout the conditions to more approximate a typical meal. Participants were instructed to consume the presented material completely and as naturally as possible.

During the typical self-feeding condition, participants fed themselves under typical eating conditions. The remaining three conditions varied on the basis of feeding independence/dependence (i.e., proprioceptive cues) and presence/absence of simulated sensory loss (i.e., exteroceptive cues). During the typical assisted feeding condition, a research assistant fed participants (i.e., removal of proprioceptive cues). During the sensory-loss self-feeding condition, participants fed themselves while blindfolded and wore 30 dB attenuation headphones (i.e., removal of visual and reduction of auditory cues). During the sensory-loss assisted feeding condition, the research assistant fed participants while participants wore the blindfold and headphones (i.e., removal/reduction of all cues). Given that the stimulus used was relatively odorless, olfaction was not addressed in the experimental protocol. Further, although gustation and somatosensation, the two remaining exteroceptive senses, play an important

role in modifying swallow movements during the oral preparatory, oral, pharyngeal, and esophageal phases, their relative contributions during the preoral stage would be expected to be limited if present at all.

Data Collection and Analysis

Hand/arm, upper lip, lower lip, and jaw movements during eating were tracked using the Optotrak Certus motion capture system (Northern Digital, Waterloo, ON, Canada). Data were collected beginning with hand/arm movement onset from a start position through the return of the hand/arm to that position. Participants began each trial with their hand in the start position and their jaw approximately closed. Small infrared-emitting diodes were placed midline on the forehead (reference point), upper and lower lips, and chin of each participant and on the dorsal surface of the index finger of the dominant hand of the participants during self-feeding and of the research assistant during assisted feeding.

Movements of the hand/arm, lips, and jaw were measured from the Optotrak outputs (x -, y -, and z -coordinates) and sampled at 250 Hz directly into the Optotrak software. The data points recorded for each sensor were extracted into ASCII files with separate files being created for each trial set. An audio signal was also simultaneously recorded (10,000 Hz sampling rate) to allow for the identification of the onset of each individual trial within the trial sets. Two different signals were generated depending on the experimental condition. To allow participants to hear the audio cue (indicator of trial onset) during the typical conditions, two metal blocks were struck together. To reduce the possibility of the participants hearing the trial onset audio cue during the sensory-loss conditions, the investigator lightly tapped the microphone.

Movement data were analyzed using custom-written Matlab (The Mathworks, Natick, MA) programs. The onset of each trial was identified by finding the peak amplitude in the audio signal. The composite three-dimensional movement waveforms for the hand/arm, lip, and jaw sensors were corrected relative to the reference point (forehead sensor) in order to account for head motion (see Figure 1). The corrected composite three-dimensional movements were expressed as the Euclidean distance between the forehead marker and the other markers of interest (hereafter referred to as *relative distance*). The identification of the onset and offset of the measures of interest are further described below.

Two potential mechanisms that lead to mouth opening in anticipation of bolus extraction are lip/jaw complex lowering and lip puckering. The focus of the current study was on lip/jaw complex lowering given the greater magnitude of movement commonly observed in this direction and the important role lowering plays in readying the mouth for bolus acceptance, especially with a pureed solid. Preliminary analyses revealed that movement of the lower lip provided the greatest level of detail regarding early oral movement as compared with the upper lip and that the

Figure 1. Sample composite three-dimensional movement waveforms for the hand/arm, lower lip, and upper lip sensors across time relative to the reference point (forehead sensory) during typical feeding.

lower lip signal effectively captured both the joint movement of the lower lip and jaw complex and the independent movement of the lower lip. Thus, only the lower lip signals were included for further analysis in the current investigation. In order to identify the onset of lip-lowering movement, the onset of movement in the *x*-dimension of the lower lip signal was used. A sample *x*-dimension lower lip tracing is presented in Figure 2; the first arrow indicates the approximate onset of lip lowering. The “offset” of anticipatory movement was defined as the point of maximal lowering or the onset of the mouth closing gesture (for bolus extraction following bolus acceptance). Offset values for lowering were also obtained from the *x*-dimension tracings (see the second arrow in Figure 2).

In addition to identifying the offset of anticipatory lip movement, or the closing of the mouth for bolus extraction, the offset of anticipatory hand movement was also defined. A movement that is closely linked to the onset of oral sensation, or the onset of the oral stage of the swallow, is a change in hand movement. During target-directed movements (e.g., reaching to grasp), two types of movement are frequently observed: an initial, fast phase during which the hand or other structure of interest is rapidly transported to the vicinity of the target and the later, slow, accurate phase during which movement velocity slows and accurate placement of the structure is achieved (Desmurget & Grafton, 2000; Hoff & Arbib, 1993). The same model can be applied to the eating process. First, the hand must be rapidly moved toward the mouth target in more of a gross-motor transportation stage that occurs primarily in the vertical plane. Once the hand nears the target, more fine-tuning is required. The movement begins to slow and change directions as the

Figure 2. 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 timings of the onset and offset of lip lowering are indicated by the first and second arrows, respectively.

hand is moved toward the mouth, ultimately resulting in the successful placement of a bolus in the oral cavity. As the transition between these two components occurs, contact is made between the lips or other oral structure and the cup/spoon/bolus, providing an individual with sensory feedback. Therefore, the temporal onset of change in hand direction, or change in goal of hand movement (i.e., from more gross motor to fine motor), was identified in addition to onset of hand movement and was used for characterizing the temporal sequence of events. The *x*-dimension tracing provided the most reliable method for identifying this change and was selected for use. A sample *x*-dimension hand tracing is presented in Figure 3; the arrow indicates the approximate timing of the change in hand direction. It should be noted that during the sensory-loss assisted feeding condition, actual lip displacement that occurred as a result of the spoon or cup making contact with the lip was visible on the tracing. These values were compared with those obtained from measuring change in hand direction to determine if this measure was an appropriate approximation for the onset of the oral stage(s) of the swallow. These two values were relatively consistent within each participant, and therefore, change in hand direction was used to approximate the time of oral sensation onset.

In all, the three primary outcome measures that were extracted from the movement tracing included anticipatory lower lip movement onset, anticipatory lower lip movement offset, and hand movement onset for feeding. To characterize temporal sequencing, a secondary value of interest was anticipatory hand movement offset or the end of the feeding gesture. Intrarater and interrater reliability measures

Figure 3. A sample movement waveform in the x-dimension (vertical movement) for the hand/arm sensor across time relative to the reference point (forehead sensor) during typical self-feeding. The approximate timing of the change in hand direction is indicated by an arrow.

were completed on approximately 20% of the data for a subset of participants (two trials within each condition; 80% of participants for intrarater and 40% for interrater). Intrarater and interrater reliability were 95.6% and 91.1%, respectively.

Experimental Design and Statistical Analysis

This study used a two-by-two, repeated-measures design. From the raw measurements described above, two primary dependent variables were calculated: relative onset and offset (time) for anticipatory lip lowering relative to hand movement onset.

Data were analyzed quantitatively and qualitatively. We used descriptive statistics to characterize the presence and temporal sequencing of anticipatory movement and independent-sample *t* tests to quantify age-related differences during typical self-feeding. We then used mixed linear models to examine the effects of and interactions between age and sensory-loss condition; age group, feeding dependency, sensory loss, and all interactions were included as fixed effects in the models. Four models were run for each variable with the best model being selected using the Akaike information criterion. When significant interactions were detected (up to $p = .10$), tests for each three-way slice (i.e., the simple effects/interactions) were completed. The Levene's Test for Equality of Variances was also used to investigate age-related differences in variability. Statistical analysis was performed using SPSS (IBM Corporation, Armonk, NY) and SAS (SAS Institute, Inc., Cary, NC).

Results

Typical Anticipatory Motor Patterns

Both younger and older adults demonstrated anticipatory mouth opening or onset of lip lowering prior to onset of oral sensation (Figure 4). However, age-related differences occurred. Older adults produced a significantly longer anticipatory lowering gesture than younger adults, $t(46) = 2.301$, $p = .026$, Cohen's $d = 0.6652$, due to earlier lip-lowering onset; that is, lip-lowering onset relative to hand onset for older adults ($M = 0.10$ s, $SD = 0.11$) occurred significantly earlier as compared with younger adults ($M = 0.30$, $SD = 0.22$), $t(46) = -3.927$, $p = .0004$, $d = 1.1499$, and offset did not differ between groups, $t(46) = -0.691$, $p = .493$. Further, older adults were significantly less variable for lip-lowering onset relative to hand onset as compared with younger adults, suggesting that this gesture was more consistently timed among the older adults, $F(1, 46) = 12.534$, $p = .001$. There were no age-related differences in hand movements.

Effects of Sensory Loss on Anticipatory Patterns

Tables 1 and 2 present the results for tests of the main and simple effects for lip-lowering onset relative to hand onset and lip-lowering offset relative to hand onset, respectively. Three-way slices are only presented for those main effects calculated to be significant. In the model generated for lip-lowering onset relative to hand onset, all fixed effects were significant ($p < .05$) except for the Age $\times$ Sensory Loss interaction (Table 1). As shown in Figure 5, older adults initiated movement significantly earlier than younger adults during typical self-feeding, sensory-loss self-feeding, and typical assisted feeding ($p = .0006$, $.0005$, and $.0005$; $d = 1.0700$, 0.5997 , and 1.1164 , respectively). No age-related differences were observed during sensory-loss assisted feeding ($p = .7277$). Older adults were less variable for lip-lowering onset relative to hand onset than younger adults during sensory-loss self-feeding, $F(1, 46) = 23.737$, $p < .001$, similar

Figure 4. Durations of anticipatory hand and lower lip movement during typical self-feeding in older and younger adults. For each movement, mean $\pm$ *SD* is presented within the duration bar.

Table 1. Statistical results for the mixed linear model test of the main and simple effects in the lip-lowering onset to hand onset variable.

Main and simple effects	Estimated difference	SE	df	Test statistic	p value
Age			1,36.3	17.02	.0002
T/SF	-0.1973	0.052	32.93	-3.80	.0006
SL/SF	-0.2931	0.074	28.42	-3.96	.0005
T/AF	-0.2438	0.065	45.09	-3.77	.0005
SL/AF	0.0219	0.062	45.79	0.35	.7277
Feeding dependency			1,104	1,694.43	<.0001
OA/typical	0.2171	0.040	34.71	5.39	<.0001
OA/SL	2.1598	0.046	28.26	46.79	<.0001
YA/typical	0.2636	0.057	41.00	4.62	<.0001
YA/SL	1.8448	0.070	33.33	26.54	<.0001
Sensory loss			1,102	1,158.57	<.0001
OA/self-feeding	-0.0185	0.028	40.75	-0.67	.5060
OA/assisted feeding	1.9242	0.053	37.61	36.14	<.0001
YA/self-feeding	0.0773	0.071	35.16	1.09	.2813
YA/assisted feeding	1.6586	0.055	39.88	30.12	<.0001
Age × Feeding Dependency			1,104	6.07	.0154
Age × Sensory Loss			1,102	2.52	.1156
Dependency × Sensory Loss			1,97.8	1,052.48	<.0001
Age × Dependency × Sensory Loss			1,97.8	11.07	.0012

Note. Simple effect analyses only completed given significant main effect; when completed, Bonferroni corrected alpha of .0125 was utilized. SE = standard error; df = degrees of freedom; T/SF = typical self-feeding; SL/SF = sensory-loss self-feeding; T/AF = typical assisted feeding; SL/AF = sensory-loss assisted feeding; OA = older adults; YA = younger adults.

to previous findings during typical self-feeding. There were also significant feeding dependency-related differences for all age/sensory-loss pairings ($p < .0001$). Lip-lowering onset was delayed during assisted feeding as compared with self-feeding. In a similar manner, there were significant sensory-loss related differences in the assisted feeding conditions for both groups ($p < .0001$) with a delay in onset occurring given sensory loss. During self-feeding, the loss of sensory cues did not significantly delay lip-lowering onset for either group. The loss of proprioception was more detrimental than the loss of exteroception, evidenced by the increased delay in lip lowering during typical assisted feeding as compared with typical self-feeding that was not present when

comparing the sensory-loss self-feeding condition to typical self-feeding.

In the model generated for lip-lowering offset relative to hand onset, the main effects for feeding dependency and sensory loss and the interaction between the two were statistically significant ($p < .05$; Table 2). There were no significant age-related differences in means or variability across conditions (see Figure 6). The presence of feeding dependency and sensory loss both resulted in delayed lip-lowering offset ($p < .0001$). Sensory-loss effects were greater during assisted feeding than when self-feeding, and the effects of feeding dependency were greater given sensory loss than when typical sensory cues were available.

Table 2. Statistical results for the mixed linear model test of the main and simple effects in the lip-lowering offset to hand onset variable.

Main and simple effects	Estimated difference	SE	df	Test statistic	p value
Age			1,48.5	0.09	.7651
Feeding dependency			1,90.7	348.45	<.0001
OA/typical	0.4877	0.056	84.19	8.73	<.0001
OA/SL	1.1665	0.106	62.52	10.97	<.0001
YA/typical	0.4617	0.056	84.19	8.27	<.0001
YA/SL	1.0662	0.106	62.52	10.02	<.0001
Sensory loss			1,90.2	569.75	<.0001
OA/self-feeding	0.7145	0.104	54.84	6.85	<.0001
OA/assisted feeding	1.3932	0.062	75.40	22.33	<.0001
YA/self-feeding	0.7245	0.104	57.84	6.95	<.0001
YA/assisted feeding	1.3290	0.062	75.40	21.30	<.0001
Age × Feeding Dependency			1,90.7	0.55	.4605
Age × Sensory Loss			1,90.2	0.10	.7566
Dependency × Sensory Loss			1,90.0	57.45	<.0001
Age × Dependency × Sensory Loss			1,90.0	0.19	.6623

Note. Simple effect analyses only completed given significant main effect; when completed, Bonferroni corrected alpha of .0125 was utilized. SE = standard error; df = degrees of freedom; OA = older adults; SL = sensory loss; YA = younger adults.

Figure 5. Lip-lowering onset times relative to hand onset for older and younger adults across four experimental conditions. SL = sensory loss. Error bars indicate 90th and 10th percentiles. All data points outside of this range are marked as outliers (shaded circles).

Discussion

This is the first study specifically aimed at investigating the effects of preoral sensorimotor cues and age on anticipatory eating-related movement. The underlying hypotheses guiding the current study were that anticipatory oral motor patterns are present during the typical eating process, preoral (nonoropharyngeal) sensorimotor cues are essential to the timely initiation of these patterns, and age negatively affects the timing of these patterns, resulting in a delayed onset in older adults as compared with younger adults. Concurrent with our hypotheses, all participants demonstrated anticipatory lip lowering under typical (sensation intact) eating conditions, and the loss of proprioception

Figure 6. Lip-lowering offset times relative to hand onset for older and younger adults across four experimental conditions. SL = sensory loss. Error bars indicate 90th and 10th percentiles. All data points outside of this range are marked as outliers (shaded circles).

and vision/audition (exteroception) differentially affected lip movement onsets and offsets. However, contrary to our hypotheses, older adults initiated earlier, generally less variable, movement than younger adults given the availability of at least one preoral sensorimotor cue.

Typical Anticipatory Motor Patterns

During typical self-feeding, all participants initiated anticipatory lip lowering during feeding-related hand movement. This agrees with previous findings of early mouth opening during “reaching to eat” tasks and supports conclusions in the limb literature of the pervasiveness of motor behaviors that occur specifically in response to the intention to act (Cattaneo et al., 2007; Fogassi et al., 2005). From a motor control standpoint, these preparatory actions help ensure task success and allow for a more efficient process (Johansson & Westling, 1988). Thus, although a bolus is prepared for the swallow during the oral preparatory stage of swallowing, the sensorimotor system itself may prepare for the swallow during this preoral stage. This would suggest a critical role for preoral cues and anticipatory actions in promoting safe, successful swallowing and eating.

Although all participants demonstrated anticipatory lip movement, older adults initiated lowering earlier than younger adults. Given that presbyphagia is frequently characterized by temporal delays (Logemann et al., 2000; Mendell & Logemann, 2007; Robbins, Coyle, Rosenbek, Roecker, & Wood, 1999; Robbins et al., 1992), it was expected that older adults in the current study would similarly demonstrate a delay in the onset of their anticipatory movements. A number of plausible explanations for the findings in the current study suggest a form of compensation. First, older adults may lower their lip/jaw complex further in anticipation of eating and thus need to start earlier in order to achieve the appropriate posture prior to food/drink reaching the mouth. A larger lowering gesture could reflect a need for greater sensory feedback (e.g., need for greater tension on jaw mechanoreceptors to interpret the proprioceptive cue received as indicating the appropriate/desired jaw position). In support, older adults show increased sensory discrimination thresholds in the oropharynx (Aviv, 1997; Chavez & Ship, 2000) and increased muscle activity during mastication (Peyron, Blanc, Lund, & Woda, 2004). Older adults also demonstrate slower, more variable upper limb movements resulting from proprioceptive declines (Adamo, Martin, & Brown, 2007). Thus, a larger lowering gesture that results in a wider mouth “target” could reduce potential burden associated with increased hand/arm precision. Second, earlier anticipatory movement onset may be necessary given slower lip/jaw movement. If there were a specific “optimal” mouth-opening gesture, invariant across age, slower moving older adults would need to begin lowering sooner in order to achieve this posture. Slower lip/jaw movement would be consistent with findings of slower limb movement and longer oropharyngeal phase duration during swallowing (Adamo et al., 2007; Logemann et al., 2000; Mendell & Logemann, 2007; Robbins et al., 1992).

In addition to earlier anticipatory lip-lowering onset, older adults also attended to this movement with greater consistency. Older adults were less variable for lip-lowering onset relative to hand onset during typical self-feeding. This finding is consistent with the explanations proposed above. That is, if it is necessary for older adults to begin lowering onset earlier, perhaps because they need to lower the lip/jaw a greater distance or they are moving slower, they will be more likely to attend to timing movement onset, particularly as related to hand movement onset.

Although presbyphagia is frequently characterized by delay, providing the basis for the hypothesis of the current investigation, a number of researchers have pointed to areas of relatively preserved function and areas indicative of potential compensations in older adults. For example, although older adults demonstrate slower tongue movement durations and lower peak lingual velocities during swallowing, tongue movement amplitudes and variability appear to be relatively unchanged (Steele & Van Lieshout, 2009). Similar to the findings here, earlier onset and increased duration of respiratory inhibition during swallowing has been reported with increasing age (Hiss, Treole, & Stuart, 2001; Leslie, Drinnan, Ford, & Wilson, 2005). It has been suggested that these changes enable older adults to compensate for other age-related changes, such as the slowing of the swallow sequence, without compromising safety. Delayed onset of hyoid movement and a more advanced pharyngeal position of the bolus head at the onset of the pharyngeal swallow may not be indicators of impairment alone as such characteristics in older adults can occur in the absence of penetration and/or aspiration and can occur in healthy younger adults (Martin-Harris, Brodsky, Michel, Lee, & Walters, 2007; Stephen, Taves, Smith, & Martin, 2005). In fact, it has been suggested that slower bolus transit and an increased number of swallows per bolus may allow older adults to compensate for changes in maximal hyoid movement, potentially providing additional protection against the risks associated with increased pharyngeal residue (Kim & McCullough, 2008). Taken together, these previous findings and the results of the current study indicate that older adults may demonstrate multiple compensatory strategies in order to enhance safety in an aging system.

Effects of Sensory Loss on Anticipatory Patterns

Nontypical sensory conditions differentially affected the timing of anticipatory gestures. Older adults initiated lip lowering relative to hand onset earlier than younger adults given either sensory loss or feeding dependency; no age-related differences were present during sensory-loss assisted feeding. Thus, although older adults demonstrated a potential “compensatory advantage” of earlier and longer anticipatory lip lowering even given partial sensory loss, it was not surprising that this advantage was eliminated when all sensory cues were decreased/diminished. Further, proprioception appeared more essential to timing lip-lowering onset; the absence of exteroceptive cues, but not self-feeding alone, delayed lip-lowering onset. The variability analyses

also support the importance of proprioception as older adults exhibited less variability than younger adults for timing lip-lowering onset to hand onset only during the self-feeding conditions.

In addition to the explanations proposed previously, these differences may also be suggestive of a more central mechanism related to motor planning/programming. During self-feeding, participants had access to the motor plan for initiating hand movement. Thus, it is plausible that the self-feeding results stem from the availability of the initial motor plan/program in addition to proprioception. The assisted feeding findings are also consistent with this suggestion. During typical assisted feeding, participants heard the auditory signal presented at trial onset, providing some information that movement was to begin, but could not access the premotor plan/program that occurred in between the signal and the feeder’s hand movement onsets. During sensory-loss assisted feeding, none of this information was available. As such, participants may have been more primed during typical assisted feeding as compared with sensory-loss assisted feeding, but, without access to the motor plan, they still demonstrated delayed onset as compared with the self-feeding conditions.

Feeding dependency and sensory loss also negatively affected lowering offsets, but no age-related differences were observed in any condition. Although proprioception was crucial in timing movement onset, exteroceptive loss was more detrimental to movement offset. Given the limited auditory information provided in the current experimental conditions (i.e., a single tone), it is likely that the results were driven by the presence/absence of visual cues more specifically. These findings are consistent with findings in the limb literature of the importance of visual feedback during the final phase of movement execution. Studies on “reaching to grasp” have demonstrated that although both vision and proprioception are necessary in timing the final phase of execution, the absence of visual feedback leads to a longer overall duration of the reaching phase, affecting transport kinematics (Gentilucci, Toni, Chieffi, & Pavesi, 1994). This increased duration may compensate for potential misreaching and/or decreases in hand velocity in the absence of vision. Although “reaching to grasp” does differ from “reaching to feed,” the overlap in these gestures is likely considerable.

Clinical Implications

These results strongly support the presence of anticipatory oral posturing that is linked to early aspects of the eating process (e.g., preswallow or preoral hand/arm movement). The oral motor system appears to ready itself for bolus acceptance (long) before food/drink nears the mouth and perhaps even before the bolus begins to move toward the mouth. This preparation begins earlier in older adults as compared with younger adults given the presence of relevant sensory cues (a “compensatory advantage”).

The implications of a loss or delay with this compensatory advantage are not entirely clear. Does a decrease in

available anticipatory preparation time result in negative consequences to the overall swallowing/eating process? It is plausible that a decrease in system readiness time could result in decreased control or coordination during the oral preparatory phase of the swallow. If the oral structures have not had their expected/necessary amount of time to prepare for bolus acceptance/extraction, they may not be ready to initiate bolus preparation when food/drink is placed in the mouth. This could result in loss of bolus control/coordination that negatively affects airway protection (e.g., anterior loss of the bolus; premature spillover into the pharyngeal cavity that may increase the risk of aspiration). Although these consequences were not overtly observed in the current study, given increased task demands (e.g., larger, more rapid bites/sips; increased environmental distractions) or an already taxed system (e.g., the presence of dysphagia or disease), such consequences may become more likely. In fact, it is not known if these anticipatory patterns look the same in a taxed system (e.g., in a medically compromised individual). It is reasonable to suggest that deficits observed during eating and swallowing that ultimately are classified broadly as “dysphagia” may stem, at least in part, from issues related to this preoral stage.

It is important to note that the loss of both proprioception and exteroception can frequently occur without actual hearing or vision impairment. A patient demonstrating decreased attention, especially in the presence of multiple environmental distractions that often occur during meals, may not hear an auditory prompt or notice a hand moving toward him or her while being fed, essentially creating a condition in which the patient cannot use typical proprioceptive and exteroceptive cues. Given that many older individuals requiring feeding assistance have other physical, sensory, or cognitive impairments, the negative impact of the absence or diminishment of such cues may be magnified. Further, the presence of chronic sensory loss as compared with the short-term imposed sensory loss used in the current study may also exaggerate the sensory-loss-related finding seen here.

Thus, it appears important to maximize preoral sensory input, especially during assisted feeding. On the basis of the current results, feeding practices should promote the availability of proprioception, vision, and audition during eating. This is supported by the findings of the importance of proprioception for timing anticipatory movement onset and vision for timing movement offset. Such strategies may include hand-over-hand feeding, verbal and/or tactile cues for increased attention to the task and priming, and decreased external distractions.

Another commonly encountered situation in which preoral sensory cues are greatly diminished or absent is during the Modified Barium Swallow Study. Given the frequent rigidity of both the examination and the testing environment, many of the typically occurring anticipatory cues are often eliminated. However, as a tool for clinical decision making, the results from the Modified Barium Swallow Study are generally extrapolated to a patient's daily and natural environments. The implications of this

type of sensory loss are not entirely known, especially as related to assessment performance and particularly in patient populations. Thus, extension of the findings from the current study to clinical practice appears to be a relevant and necessary next step for future research.

Limitations

A few limitations of the current study are worth noting. This study focused on lip/jaw movement, yet the tongue plays a highly important role in bolus preparation and oral transit. Multiple patterns of tongue movement occur in response to factors such as bolus consistency, and the tongue acts synergistically with the jaw during mastication (Steele & Van Lieshout, 2008). Respiratory coordination is also important. Limited previous literature has identified the potential for anticipatory respiratory patterns (Martin-Harris et al., 2005; Selley, Flack, Ellis, & Brooks, 1990). Thus, future investigations of eating-related anticipatory movement should also include lingual and respiratory actions.

Further, the experimental paradigm did not replicate a completely naturalistic setting (e.g., specified start position, special utensils, predetermined bolus size, lack of olfactory cues). Although these modifications were necessary to minimize confounding variables, they may have affected the overall results. However, given the highly significant age- and sensory-related differences seen (e.g., up to a large effect size), it may be argued that similar findings would be seen in more naturalistic settings.

Conclusions

Anticipatory mouth movements during swallowing/eating are important to consider, particularly for older adults. As older adults consistently demonstrated a “compensatory advantage” through earlier and less variable lip/mouth movement onset given available preoral sensorimotor cues, continued investigation into these age-related differences is necessary. It is unclear how the differences observed between older and younger adults contribute to continued swallow safety with advancing age and if these differences, particularly under conditions of sensory loss, may be further exacerbated in a nonhealthy system (e.g., concomitant disease or dysphagia). This study represents a first step in clarifying the relationship between preoral cues and anticipatory mouth posturing during eating and swallowing, allowing for a better understanding of the potential for increased risk that assisted feeding recommendations and other feeding and swallowing practices may elicit, particularly for older adults with dysphagia.

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References

- Adamo, D. E., Martin, B. J., & Brown, S. H. (2007). Age-related differences in upper limb proprioceptive acuity. *Perceptual and Motor Skills*, 104, 1297–1309.
- Altman, K. W., Yu, G. P., & Schaefer, S. D. (2010). Consequence of dysphagia in the hospitalized patient: Impact on prognosis and hospital resources. *Archives of Otolaryngology—Head & Neck Surgery*, 136, 784–789.
- Amella, E. J. (2004). Feeding and hydration issues for older adults with dementia. *Nursing Clinics of North America*, 39, 607–623. doi:10.1016/j.cnur.2004.02.014
- Aviv, J. E. (1997). Effects of aging on sensitivity of the pharyngeal and supraglottic areas. *The American Journal of Medicine*, 103(5, Suppl. 1), 74S–76S.
- Aziz, S. J., & Campbell-Taylor, I. (1999). Neglect and abuse associated with undernutrition in long-term care in North America: Causes and solutions. *Journal of Elder Abuse & Neglect*, 10, 91–117. doi:10.1300/J084v10n01_07
- Besier, T. F., Lloyd, D. G., Ackland, T. R., & Cochrane, J. L. (2001). Anticipatory effects on knee joint loading during running and cutting maneuvers. *Medicine and Science in Sports Education*, 33, 1176–1181.
- Cabre, M., Serra-Prat, M., Force, L., Almirall, J., Palomera, E., & Clave, P. (2014). Oropharyngeal dysphagia is a risk factor for readmission for pneumonia in the very elderly persons: Observational prospective study. *Journals of Gerontology: Series A: Biological Sciences and Medical Sciences*, 69, M330–M337. doi:10.1093/gerona/glt099
- Cattaneo, L., Fabbri-Destro, M., Boria, S., Pieraccini, C., Monti, A., Cossu, G., & Rizzolatti, G. (2007). Impairment of actions chains in autism and its possible role in intention understanding. *Proceedings of the National Academy of Sciences of the United States of America*, 104, 17825–17830. doi:10.1073/pnas.0706273104
- Chadwick, D. D., Jolliffe, J., & Goldbart, J. (2003). Adherence to eating and drinking guidelines for adults with intellectual disabilities and dysphagia. *American Journal on Mental Retardation*, 108, 202–211.
- Chang, C. C., & Roberts, B. L. (2008). Feeding difficulty in older adults with dementia. *Journal of Clinical Nursing*, 17, 2266–2274. doi:10.1111/j.1365-2702.2007.02275.x
- Chavez, E., & Ship, J. (2000). Sensory and motor deficits in the elderly: Impact on oral health. *Journal of Public Health Dentistry*, 60, 297–303.
- Desmurget, M., & Grafton, S. (2000). Forward modeling allows feedback control for fast reaching movements. *Trends in Cognitive Sciences*, 4, 423–431.
- Dey, A. N. (1997). Characteristics of elderly nursing home residents: Data from the 1995 national nursing home survey. *Advance Data from Vital and Health Statistics of the Centers for Disease Control and Prevention/National Center for Health Statistics*, 289, 1–8.
- Ebihara, T., Ebihara, S., Maruyama, M., Kobayashi, M., Itou, A., Arai, H., & Sasaki, H. (2006). A randomized trial of olfactory stimulation using black pepper oil in older people with swallowing dysfunction. *Journal of the American Geriatrics Society*, 54, 1401–1406.
- Edaheiro, A., Hirano, H., Yamada, R., Chiba, Y., Watanabe, Y., Tonogi, M., & Yamane, G. Y. (2012). Factors affecting independence in eating among elderly with Alzheimer's disease. *Geriatrics & Gerontology International*, 12, 481–490. doi:10.1111/j.1447-0594.2011.00799.x
- Elsner, R. J. F. (2002). Changes in eating behavior during the aging process. *Eating Behaviors*, 3, 15–43.
- Emond, M., & Weingarten, H. (1995). Fos-like immunoreactivity in vagal and hypoglossal nuclei in different feeding states: A quantitative study. *Physiology & Behavior*, 58, 459–465.
- Fogassi, L., Ferrari, P. F., Gesierich, B., Rozzi, S., Chersi, F., & Rizzolatti, G. (2005, April 29). Parietal lobe: From action organization to intention understanding. *Science*, 308, 662–667. doi:10.1126/science.1106138
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-Mental State": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12, 189–198.
- Gentilucci, M., Toni, I., Chieffi, S., & Pavesi, G. (1994). The role of proprioception in the control of prehension movements: A kinematic study in a peripherally deafferented patient and in normal subjects. *Experimental Brain Research*, 99, 483–500.
- Hiss, S. G., Treole, K., & Stuart, A. (2001). Effects of age, gender, bolus volume, and trial on swallowing apnea duration and swallow/respiratory phase relationships of normal adults. *Dysphagia*, 16, 128–135.
- Hoff, B., & Arbib, M. A. (1993). Models of trajectory formation and temporal interaction of reach and grasp. *Journal of Motor Behavior*, 25, 175–192.
- Howden, C. W. (2004). Management of acid-related disorders in patients with dysphagia. *The American Journal of Medicine Supplements*, 117(5, Suppl. 1), 44–48. doi:10.1016/j.amjmed.2004.07.017
- Johansson, R. S., & Westling, G. (1988). Programmed and triggered actions to rapid load changes during precision grip. *Experimental Brain Research*, 71, 72–86.
- Kim, Y., & McCullough, G. H. (2008). Maximum hyoid displacement in normal swallowing. *Dysphagia*, 23, 274–279.
- Langmore, S., Terpenning, M. S., Schork, A., Chen, Y., Murray, J. T., Lopatin, D., & Loesche, W. J. (1998). Predictors of aspiration pneumonia: How important is dysphagia? *Dysphagia*, 13, 69–81.
- Leopold, N. A., & Kagel, M. C. (1983). Swallowing, ingestion and dysphagia: A reappraisal. *Archives of Physical Medicine and Rehabilitation*, 64, 371–373.
- Leopold, N. A., & Kagel, M. C. (1997). Dysphagia—Ingestion or deglutition? A proposed paradigm. *Dysphagia*, 12, 202–206.
- Leslie, P., Drinnan, M. J., Ford, G. A., & Wilson, J. A. (2005). Swallow respiratory patterns and aging: Presbyphagia or dysphagia? *Journals of Gerontology: Series A: Biological Sciences and Medical Sciences*, 60, M391–M395.
- Lin, L. C., Watson, R., & Wu, S. C. (2010). What is associated with low food intake in older people with dementia? *Journal of Clinical Nursing*, 19, 53–59. doi:10.1111/j.1365-2702.2009.02962.x
- Logemann, J. A. (1998). *Evaluation and treatment of swallowing disorders*. Austin, TX: Pro-Ed.
- Logemann, J. A., Pauloski, B. R., Rademaker, A. W., Colangelo, L. A., Kahrilas, P. J., & Smith, C. H. (2000). Temporal and biomechanical characteristics of oropharyngeal swallow in younger and older men. *Journal of Speech, Language, and Hearing Research*, 43, 1264–1274.
- Maeda, K., Ono, T., Otsuka, R., Ishiwata, Y., Kuroda, T., & Ohyama, K. (2004). Modulation of voluntary swallowing by visual inputs in humans. *Dysphagia*, 19, 1–6.
- Martin-Harris, B., Brodsky, M. B., Michel, Y., Ford, C. L., Walters, B., & Heffner, J. (2005). Breathing and swallowing dynamics across the adult lifespan. *Archives of Otolaryngology—Head & Neck Surgery*, 131, 762–770.

- Martin-Harris, B., Brodsky, M. B., Michel, Y., Lee, F. S., & Walters, B.** (2007). Delayed initiation of the pharyngeal swallow: Normal variability in adult swallows. *Journal of Speech, Language, and Hearing Research, 50*, 585–594.
- Martino, R., Foley, N., Bhogal, S., Diamant, N., Speechley, M., & Teasell, R.** (2005). Dysphagia after stroke: Incidence, diagnosis, and pulmonary complications. *Stroke, 36*, 2756–2763. doi:10.1161/01.STR.0000190056.76543.eb
- Mendell, D. A., & Logemann, J. A.** (2007). Temporal sequence of swallow events during the oropharyngeal swallow. *Journal of Speech, Language, and Hearing Research, 50*, 1256–1271.
- Ney, D. M., Weiss, J. M., Kind, A. J., & Robbins, J.** (2009). Senescent swallowing: Impact, strategies, and interventions. *Nutrition in Clinical Practice, 24*, 395–413. doi:10.1177/0884533609332005
- Nguyen, N., Frank, C., Moltz, C., Vos, P., Smith, H., Karlsson, U., ... Sallah, S.** (2005). Impact of dysphagia on quality of life after treatment of head-and-neck cancer. *International Journal of Radiation Oncology, Biology, Physics, 61*, 772–778.
- Peyron, M., Blanc, O., Lund, J., & Woda, A.** (2004). Influence of age on adaptability of human mastication. *Journal of Neurophysiology, 92*, 773–779.
- Robbins, J., Coyle, J., Rosenbek, J., Roecker, E., & Wood, J.** (1999). Differentiation of normal and abnormal airway protection during swallowing using the Penetration-Aspiration Scale. *Dysphagia, 14*, 228–232.
- Robbins, J., Hamilton, J. W., Lof, G. L., & Kempster, G. B.** (1992). Oropharyngeal swallowing in normal adults of different ages. *Gastroenterology, 103*, 823–829.
- Roy, N., Stemple, J., Merrill, R. M., & Thomas, L.** (2007). Dysphagia in the elderly: Preliminary evidence of prevalence, risk factors, and socioemotional effects. *Annals of Otology, Rhinology & Laryngology, 116*, 858–865.
- Selley, W. G., Flack, F. C., Ellis, R. E., & Brooks, W. A.** (1990). The Exeter dysphagia assessment technique. *Dysphagia, 4*, 227–235.
- Sherrington, C. S.** (1906). *The integrative action of the nervous system*. New Haven, CT: Yale University Press.
- Siebens, H., Trupe, E., Siebens, A., Cook, F., Anshen, S., Hanauer, R., & Oster, G.** (1986). Correlates and consequences of eating dependency in institutionalized elderly. *Journal of the American Geriatrics Society, 34*, 192–198.
- Steele, C. M., & Miller, A. J.** (2010). Sensory input pathways and mechanisms in swallowing: A review. *Dysphagia, 25*, 323–333. doi:10.1007/s00455-010-9301-5
- Steele, C. M., & Van Lieshout, P. H.** (2008). The dynamics of lingual-mandibular coordination during liquid swallowing. *Dysphagia, 23*, 33–46. doi:10.1007/s00455-007-9093-4
- Steele, C. M., & Van Lieshout, P. H.** (2009). Tongue movements during water swallowing in healthy young and older adults. *Journal of Speech, Language, and Hearing Research, 52*, 1255–1267.
- Stephen, J. R., Taves, D. H., Smith, R. C., & Martin, R. E.** (2005). Bolus location at the initiation of the pharyngeal stage of swallowing in healthy older adults. *Dysphagia, 20*, 266–272.
- U.S. Department of Health and Human Services.** (2014). A profile of older Americans: 2013. Retrieved from http://www.aoa.acl.gov/Aging_Statistics/Profile/2013/docs/2013_Profile.pdf