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Review A review of swallow timing in the elderly



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ABSTRACT

Many studies evaluate dysphagia in elderly patients and compare their swallowing to younger controls to assess the degree of swallowing impairment. Previous research suggests that changes should be expected in swallowing due to aging, and these changes need to be considered when performing swallowing assessments. A systematic review was conducted to elucidate the timing of swallowing in healthy. A comprehensive multiengine literature search was conducted to find articles studying swallowing in the healthy elderly, which yielded 22,852 articles of which 11 were judged to be relevant. Only articles using videofluoroscopy as an assessment method for swallowing timing were included. The articles underwent detailed review for study quality and data extraction. The eleven studies contained data for 32 different parameters, and 10 of the 11 studies compared elderly subjects to a younger group. Timing measures from the studies were compiled for analysis. In general, bolus transit times do not appear to change with age. Of note, elderly subjects tended to have a significantly delayed swallow response times and longer duration of upper esophageal sphincter opening. Results showed a large degree of variability across studies for each of the timing measures. Confidence intervals for timing in healthy older participants were computed across studies. Potential sources of variation were identified, including methodological, stimulus-related and participant-related sources. The results suggests that aging affects only a few very specific swallowing timing parameters, and many parameters appear to be unaffected by aging. Therefore, significant differences from a young reference sample should be interpreted as dysphagia rather than normal changes due to aging.

1. Introduction

It is well known that as we age our bodies undergo some physiological changes that may not be due to illness or disease; rather, they are simply due to natural aging. In the exercise science literature, agerelated sarcopenia is well documented (e.g. [1-3]), but it is not as clearly described in the deglutition literature. The term sarcopenia is used to describe the loss of muscle mass and strength that occurs with aging. Sarcopenia is believed to play a major role in the pathogenesis of frailty and functional impairment that occurs with old age, particularly in the seventh decade and beyond [4]. It has been reported that after 70 years of age, 0.5% to 1.0% of overall muscle mass is lost per year, with a 4.7% loss compared with peak mass in men and 3.7% loss in women per decade [4]. Overall strength of the limb muscles is also reported to decline by 10% to 15% per decade up to the age of 70 years, after which the loss accelerates to 25% to 40% per decade [5,6].

There are also natural physiological changes involved in the aging neuromotor system. The elderly are reported to suffer from the loss of cortical neurons and altered synaptic connections [7], a reduced number of motor units [8] and muscle fibres [9], and altered discharge characteristics of motor units [10]. These changes directly affect motor output, in the form of slower and more variable movements [11,12], decreased amplitude of movement with increased variability [8] and increased latency of response to sensory stimuli [13-15]. Much of this research has been done on the limb musculature, but studies suggest that the orofacial motor system is similarly affected. The elderly are reported to exhibit less accurate speech movements [16], more variable orofacial movements [17,18], and slower and more variable tongue movements during swallowing [19]. It is logical to assume that many of the muscles involved in swallowing may also be affected by aging, even in the absence of other underlying health issues. The muscles of the oropharynx are skeletal, striated muscles and therefore, age-related loss and atrophy might be expected in these muscles, similar to that seen in the limb muscles, despite the fact that the muscles of the head and neck are not weight bearing.

While the literature contains many descriptions of dysphagia in

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Criteria for abstract review.

Inclusion criteria
The study appears to report on healthy subjects.
The study appears to report on elderly subjects (60 + years).
The study appears to report on timing measures of swallowing.
The study appears to use video fluoroscopy swallowing studies to evaluate timing.
The study appears to be an original experiment.
Exclusion criteria
The study analyzes the elderly, but does not parse out the results from those of the
younger subjects.
The study is a review article.
The elderly subjects in the study are not healthy.
There are no elderly subjects in the study.
The study reports on swallowing measures that are not timing related.

individuals with neurological diagnoses (stroke [20,21], brain injury [22,23], Parkinson's disease [24,25], etc.) or following head and neck cancer [26,27]), physiological changes in swallowing that occur in the course of healthy aging (presbyphagia) are not as clearly understood. When clinicians identify dysphagia in elderly patients, the reference perspective is usually that of the swallowing mechanism in much younger, healthy individuals. It may be more appropriate to compare the swallowing of elderly patients to elderly community-dwelling individuals who are otherwise healthy. The dysphagia literature has clearly pointed to reduced muscle strength in the tongue with aging [28,29], but evidence regarding age-related changes in timing measures has been slightly more elusive.

Several studies in the literature describe age-related changes in swallowing (e.g., [30-39]). However, studies in which measures of

swallow timing are reported, typically involve small sample sizes, or have looked at specific aspects of swallowing rather than following the bolus from the point of entry into the oral cavity to the point at which the bolus tail passes into the esophagus. Timing is of particular importance, as a safe and efficient swallow relies on precise timing and coordination of muscle contraction across a series of at least 15 bilateral pairs of muscles in the oropharynx. Given the previously mentioned changes in the aging neurosystem, it is likely that the timing of the swallow is altered with age and it is important to determine if these alterations are of any clinical relevance. Recently, Molfenter and Steele [40] performed a meta-analysis of the variability seen in three commonly-used durational parameters and three commonly-used interval parameters from studies of healthy swallowing using videofluoroscopy. Their results alluded to age-related changes for some parameters in the elderly but they did not specifically parse out the data from that of younger subjects, nor did they consider all possible timing measures. The goal of the current review and analysis was to synthesize the results of published studies reporting swallow timing measures from videofluoroscopy in healthy, older adults, with no signs of dysphagia, in order to establish reference values for elderly with normal aging. A secondary objective was to compare these reference data to the data presented for healthy younger controls in the same set of studies, where available. For the purposes of this review, we define the term "elderly" as referring to adults over the age of 60 and defined "healthy" participants as those who were reported to be free of dysphagia and disease.

> Fig. 1. A PRISMA flow diagram depicting the flow of information through the different phases of the systematic review, mapping out the number of records identified, included and excluded.



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Authors	Year	Title	Source	n N	fin age yrs) old	Max age (yrs) old	Mean age (yrs) old	Compared to young?	Mean age/age range (yrs) young
Dejaeger, Pelemans, Bibau & Ponette Im, Kim, Oommen, Kim & Ko	1994 2012	Manofluorographic analysis of swallowing in the elderly The effects of bolus consistency in pharyngeal transit duration	Hand search Database search	16 20 6	I	89	80 77.25	>>	28 ± 8 26 ± 6
Kang, Oh, Kim, Chung, Kim & Han	2010	during normal swallowing Influence on aging on movement of the hyoid bone and epiglottis	Hand search	16 6	υ		71	>	35 ± 8
Kendall, Leonard & McKenzie	2004	during notinal swanowing, a motion analysis Common medical conditions in the elderly: impact on pharyngeal	Database search	23 6	5			х	N/A
Kem, Bardan, Arndorfer, Hofmann, Ren & Shaker	1999	bolus transit Comparison of upper esophageal sphincter opening in healthy	Hand search	14 7	0	06	75	>	33 ± 3
Kim, McCullough & Asp	2005	asymptomatic young and elderly volumeers Temporal measurements of pharyngeal swallowing in normal	Database search	20 7	0	87		>	21-51
Leonard, Kendall & McKenzie	2004	populations UES opening and cricopharyngeal bar in nondysphagic elderly	Database search	23 6	υ	88		>	18–57
Leonard & McKenzie	2006	and nonelderly adults Hyoid-bolus transit latencies in normal swallow	Database search	23 6	ŭ	88		>	18–57
Logemann, Pauloski, Rademaker, Colangelo, Kahrilas & Smith	2000	Temporal and biomechanical characteristics of oropharyngeal swallow in vounger and older men	Database search	8	Q	94		>	21-29
Logemann, Pauloski, Rademaker & Kahrilas	2002	Oropharyngeal swallow in younger and older women: videofluorosconic analvsis	Database search	8	Q	93		>	21–29
Mendell & Logemann	2007	Temporal sequence of swallow events during the oropharyngeal swallow	Hand search	60 6	Q			>	20-29
In this table, 'n' refers to the number of healthy eld	lerly par	tticipants in the study.							

2. Methods

2.1. Search strategy and inclusion criteria

A comprehensive literature search was carried out by a trained librarian in February 2016 to find reports of normal swallowing physiology in independent, elderly individuals residing in the community. Since the focus of this review was specifically on timing measures of swallowing physiology, the search was restricted to articles in which videofluoroscopy had been used to evaluate swallowing. Videofluorsocopic swallowing studies are widely considered the gold standard method for evaluating swallowing, and generally use a standardized protocol to analyze several different quantitative parameters. This method of assessment allows one to simultaneously view the both the movements of the bolus along with the structures of the head and neck. This makes it easier to compare results, which is why it was the chosen method of instrumentation for the present study. The electronic retrieval systems and databases searched for relevant articles were Medline, Medline In Process, Embase, CENTRAL, CINAHL, and Pubmed Supplemental Search. Search strategies for each database were developed with input from the librarian. The keywords (Medical Subject Headings in Medline) used were: deglutition disorders, deglutition, dysphagi*, swallow*, deglutition*, presbyphagi*, age factors, aging, aged, elder, elderly, geriatric, older, and senescent. These terms were used isolation or in different combinations using Boolean operators. Terms were nominated by the first and last authors and the librarian, and intended to capture terms and concepts known to be used in the swallowing and aging research communities to describe normal swallowing physiology in healthy, elderly individuals.

The search was limited to human studies published from the inception of each database to February 2016. Studies were considered eligible if (1) healthy participants were over the age of 60 were included: (2) the study reported on measures of swallow timing based on videofluoroscopy; (3) the study provided descriptive statistics (means and either standard deviations [SD] or standard error of the mean [SEM]) for temporal parameters during thin-liquid swallowing tasks; (4) the study was written in English; and (5) the study was published in a peer-reviewed journal. Studies were excluded if (1) they did not have an elderly, healthy sample; (2) the subjects were tube-fed; (3) the subjects were not community-dwelling, indicating that they might have some health issues; (4) methods other than videofluroscopy were used to capture timing measures. The first author screened titles and then abstracts were screened for key words using the functions within EndNote. The second author assisted with abstract reviews. Inter-rater agreement regarding relevance was calculated for 45% (i.e. 320 of 714 abstracts) of the abstracts based on blinded completion of abstract reviews using the criteria listed in Table 1.

To ensure completeness and thoroughness, the reference lists of all qualified articles from the database search were hand-searched for additional studies that discussed swallow timing in the elderly. The same inclusion and exclusion criteria were applied to this list of handsearched articles. The final set of included articles underwent detailed review for study quality and data extraction.

2.2. Risk of bias

An evaluation of risk of bias was performed according to the guidelines suggested by the Cochrane Bias Methods Group [41]. Each included study was reviewed independently by both the first and second authors to determine whether there was potential bias. Reliability for risk of bias decisions between the two reviewers was 100%. Bias was assessed in terms of blinding, timing of assessments, attrition or missing data, and reporting of results.

Risk of bias table.

Authors	Year	Risk of bias?	Type of bias
Dejaeger, Pelemans, Bibau & Ponette	1994	+	No mention of reliability of ratings or blinding. Insufficient information to permit judgment of selective outcome reporting. Young group was explicitly said to be healthy while elderly group was only free of disease known to influence deglutition, so not necessarily healthy.
Im, Kim, Oommen, Kim & Ko	2012	+	No mention of reliability of ratings or blinding. Insufficient information to permit judgment regarding selective outcome reporting; methods discuss number of participants but results do not mention number of participants.
Kang, Oh, Kim, Chung, Kim & Han	2010	+	Not enough information provided in order to determine if raters were blinded to participant age. Insufficient information to permit judgment regarding selective outcome reporting. Dropout rate was not described.
Kendall, Leonard & McKenzie	2004	+	Number of participants in methods does not match number of participants in results.
Kern, Bardan, Arndorfer, Hofmann, Ren & Shaker	1999	+	Dropout rate was not described and there was insufficient information to permit judgment regarding selective outcome reporting.
Kim, McCullough & Asp	2005	+	No mention of blinding of raters. Insufficient information to permit judgment regarding selective outcome reporting; methods discuss number of participants but results do not mention number of participants.
Leonard, Kendall & McKenzie	2004	+	No mention of blinded ratings. Insufficient information to permit judgment regarding selective outcome reporting; methods discuss number of participants but results do not mention number of participants.
Leonard & McKenzie	2006	+	No mention of reliability of ratings or blinding. Insufficient information to permit judgment regarding selective outcome reporting; methods discuss number of participants but results do not mention number of participants.
Mendell & Logemann	2007	+	It is unknown whether the outcome assessor was blinded to the age of the participants. Insufficient information to permit judgment regarding selective outcome reporting or to know if groups were similar at baseline. Timing of the assessment is unknown.
Logemann, Pauloski, Rademaker, Colangelo, Kahrilas & Smith	2000	+	No mention of blinded ratings. Insufficient information to permit judgment regarding selective outcome reporting; methods discuss number of participants but results do not mention number of participants.
Logemann, Pauloski, Rademaker & Kahrilas	2002	+	No mention of blinded ratings. Insufficient information to permit judgment regarding selective outcome reporting; methods discuss number of participants but results do not mention number of participants.

A '+' symbol indicates that the study is at risk of bias, and the '-'symbol indicates no risk of bias.

2.3. Data extraction

In order to facilitate comparisons of timing parameter data across the literature, the mean values for each timing measure were extracted from the publications in order to assist with the creation of forest plots. This review will focus only on data for thin liquid swallowing in the elderly, although many of these studies also reported data for other measures (e.g., spatial measures) and stimuli. All timing units were converted to seconds for uniformity. The corresponding measure of dispersion, standard deviation (SD) or standard error of the mean (SEM), was also extracted from each publication. In cases where SD was unavailable, the SEM was used to calculate SD. Next, 95% confidence intervals for the mean of each study/parameter were derived. This was achieved by multiplying a specific *t*-value (two-tailed, a = 0.05, at n – 1 df) by the SD/[SQRT(n)]. The product of this equation, added or subtracted from the mean, gives the 95% confidence interval for that specific mean.

3. Results

Fig. 1 summarizes the yield of the literature search strategy according to the criteria laid out in the 2009 PRISMA guideline for systematic reviews [42]. Inter-rater agreement regarding inclusion and exclusion of abstracts was 92% (Kappa score = 0.76). Of the 22,852 records identified, 11 articles were eligible and included in the review. Six articles were found through the database search, and an additional five articles were found by searching through the reference lists of the initial six articles. A brief summary of the articles included in this review, including authors, year of publication, title and participant ages, is provided in Table 2.

As denoted by the '+' symbols in Table 3, for the 11 studies reviewed, risks of bias were identified for every study. The most common risk of bias lay in the failure to report reliability of ratings or disclose

whether ratings had been made in a blinded fashion. Agreement across raters is important not only for calculating durational measures but in selecting the frames that are used to index such measures; this was rarely reported. Moreover, for studies with both old and young participant groups, or any stratification of groups that might have different presentations with respect to swallow timing, blinding to stratum is important so that ratings are not biased. Another important risk of bias was the failure to mention whether all participants recruited actually completed the study. Based on these limitations, caution is warranted in drawing generalized conclusions from this body of literature.

Table 4 lists the 32 different timing events that were identified across the selected articles, and used as the basis for calculating timing interval measures. As shown in the far right column of Table 4, it was not unusual to find several different names or descriptions used to refer to a single event; subcomponent events were also identified in several cases. The events in Table 4 are listed in a rostro-caudal physiological sequence and are further classified into either bolus events or physiological, or "gesture", events [43]. Tables 5-8 list the 40 different timing interval measures that were found in the 11 articles included in the review, grouped into four different categories: a) bolus transit parameters (Table 5); b) parameters referencing the onset of hyoid excursion to bolus events (Table 6); c) pharyngeal phase parameters referenced to the bolus entering the pharynx (Table 7); and d) pharyngeal phase parameters referenced to gesture events (Table 8). Definitions for each timing parameter are shown based on onset and offset events, using the higher-order event labels from Table 4. Some of the resulting timing parameters refer to bolus events only, some to gesture events only, and others combine bolus and gesture events.

Ten of the eleven studies compared elderly participants to a younger, healthy group; where the data were available, these comparisons will be highlighted. All of the parameters, as well as their respective mean timings and confidence intervals can be referenced in Tables A.1–A.4. All studies reported the quantitative data necessary to

Events used in the calculation of timing parameters.

_	Event	Description	Sub-events	Also described as
_	Instruction 1	Command to swallow	N/A	N/A
	Bolus_1	Bolus leaves the oral cavity and enters the pharynx	B1a	First bolus movement past the posterior nasal spine that leads to a swallow; Head of the bolus
				past the nasal spine; Bolus past the posterior nasal spine.
			B1b	First backward movement of the bolus associated with the swallow
			B1c	Passage of bolus past the level of the tonsillar pillars
			B1d	Bolus entering the pharynx
			Ble	Arrival of the bolus head at the tongue base; First frame showing the bolus head reaching the
				tongue base the point it crosses the ramus of the mandible; Bolus head reaches the point
			D16	where the lower edge of the mandible crosses the tongue base.
			БП	bolus passing the posterior edge of the ramus, bolus head passing the mandible, bolus past
	Polue 2	Polya reaches the level of the vallegulae	PDo	Arrival of the below in the vallegulace Head of the below first arrival at the vallegulace
	Bolus_2	Bolus leaches the level of the valleculae	D2a P2b	Relya head passes the vallegulae.
	Bolue 2	Rolus passes the level of the vallegulae	B2D B2o	Head of the bolus first arrives at the inferior border of the vallegulae
	bolus_5	bolus passes the level of the valieculae	B3b	Head of the bolus wited or passed the valleculae
	Bolus 4	Bolus arrives at the entrance to the larvay	N/A	N/A
	Bolus 5	Bolus arrives at the upper pyriform sinuses	N/A	N/A
	Gesture 1	Onset of hvoid excursion	N/A	Hyoid onset: Initial movement of the byoid leading to a swallow: Initial movement of byoid:
				First frame showing hyoid elevation (first displacement in movement associated with a
				swallow): Initiation of hvoid movement regardless of direction.
	Gesture 2	Onset of superior laryngeal movement	N/A	Larvngeal elevation begins in the context of the rest of the swallow; First larvngeal elevation
	-	1 50		in the swallow; First frame showing onset of laryngeal elevation (first displacement in
				movement at the area of the posterior vocal folds and arytenoids associated with the
				swallow); Vertical laryngeal movement.
	Gesture_3	Onset of epiglottic deflection	N/A	Initiation of epiglottic rotation
	Gesture_4	Onset of laryngeal vestibule closure	G4a	Onset of vestibular closure; First laryngeal vestibule closure; First frame showing complete
				laryngeal closure (complete elimination of air space from the laryngeal vestibule); Closure of
				the laryngeal vestibule.
			G4b	Onset of supraglottic closure; Down-folding of epiglottis closing off the supraglottic passage;
				Point when the down-folding epiglottis was seen to approximate the arytenoid cartilages.
	Gesture_5	Onset of base of tongue retraction	N/A	First frame showing onset of tongue base movement toward the PPW; Posterior tongue
				movements at the level opposite the anterior-inferior corner of the C2 vertebrae.
	Gesture_6	Tongue contact at posterior pharyngeal wall	N/A	N/A
	Gesture_7	Posterior pharyngeal wall movement	N/A	Anterior movement of the powerior pharyngeal wall at the level of the anterior-inferior corner
	Castura 9	Orest of UES anoning	D71	of the C2 vertebrae
	Gesture_8	Unset of UES opening	B/D B7a	Passage of the bolus fail through the cess, bolus clearing the CES.
			D/C	First frame indicating crisopharungeal opening: First crisopharungeal opening:
			14/14	Cricopharyngeal opening: UES opening
	Gesture 9	Maximal excursion of byoid motion	N/A	N/A
	Bolus 6	Bolus passing into the upper esophageal sphincter	N/A	Bolus head first enters UES
	Bolus 7	Bolus exits from the UES into the esophagus	B7a	Passage of the bolus tail into the UES
	Gesture 10	Maximal cricopharyngeal opening	N/A	N/A
	Gesture 11	Base of tongue comes off the PPW	N/A	N/A
	Gesture_12	Resting closed state of the UES following the passage	N/A	Cricopharyngeal closing; UES closing
	-	of the tail of the swallowed bolus		0. 0
	Gesture_13	Opening of the laryngeal vestibule	N/A	Opening of the supraglottic space
	Gesture_14	Hyoid return to rest	N/A	N/A

Table 5

Study key for bolus transit parameters.

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Study key for swallow reaction parameters referencing the onset of hyoid excursion to bolus events.

Ref. number	First author	Year	Name of parameter	Grouping onset event	Grouping offset event	Vol (cc)
[51]	Leonard	2006	Onset of bolus transit	B1	G1	3
[52]	Kim	2005	Stage transition duration	B1	G1	20 5 10
[51]	Leonard	2006	Bolus past mandible	B1	G1	3
[50] [51]	Kang Leonard	2010 2006	Onset of hyoid excursion Bolus at valleculae	B1 B2	G1 G1	20 2 3
[51]	Leonard	2006	Bolus exiting or passing the valleculae	B3	G1	20 3 20
[51]	Leonard	2006	Bolus at UES	B6	G1	3 20

calculate confidence intervals to support the creation of forest plots for the different timing measures, which can be found in Figs. 2–6. The error bars in each figure represent the spread of the 95% confidence interval. The scales are held constant to enable transparent comparison across measures. A study number in square brackets, which is the same as the reference number, can be found beside each data point. Each data point represents a parameter that differs in either study, parameter, age group, and/or bolus size, and points are grouped based on similar definitions. It is important to note that many of the definitions are not identical but have been grouped based on comparable onset and offset events; these groupings can be found in Table 4. The study key can be found within Tables 5–8. An asterisk beside the study number is indicative of a significant difference between the young and elderly group in that study.

3.1. Bolus transit parameters

A single study reported data for bolus transit through the oral cavity [44]. This parameter was called "deglutition delay" and was defined as the interval from the command-to-swallow to the passage of the bolus past the level of the tonsillar pillars. The mean value for elderly participants was 1.70 s (95% confidence interval: 0.86–2.53), which was significantly longer than the values seen in a younger control group: mean = 0.50 s (95% CI: 0.37–0.63).

Bolus transit times through different portions of the pharynx were measured in 6 studies using a total of 9 different parameters, which are illustrated in Fig. 2. For all of these parameters, both the onset and offset events were determined based on bolus position or flow. The elderly groups have visibly increased variability in timing for the interval between the bolus passing the mandible and arriving at the inferior valleculae (B1 to B3). Only two parameters were reported to show significant differences between older and younger participants: pharyngeal transit duration (B1 to B6) with a 5 cm³ bolus [45] and

Table 7

Study key for pharyngeal phase parameters referenced to the bolus entering the pharynx.

hypopharyngeal transit time (B2 to B7) with a 20 cm³ bolus [35]. It is important to note that some of the studies did not report timing measures for a younger group so these same comparisons could not be made. However, given the few scattered reports of age-related changes in bolus transit parameters and the absence of a more pervasive trend, it is possible that these parameters may not change over the course of the lifespan.

3.2. Swallow reaction parameters

In between the end of the oral phase of swallowing and the beginning of the pharyngeal phase is an interval that has become commonly known as stage transition duration[47], reflecting a timeframe when the bolus can be seen in the pharynx prior to the initiation of the pharyngeal swallow. Timing measures of this interval are sometimes called swallow response time [48] and are considered to reflect integrity of the timing of swallow initiation. More specifically, swallow response time refers to the time from the arrival of the bolus head at the hypopharynx to the onset of laryngeal elevation. Other researchers, including Logemann and her trainees, have referred to swallow response time as the duration of the pharyngeal motor response, rather than initiation of the motor response [24,36,37,46,48]. For the purposes of this paper, swallow reaction parameters will refer to measures that describe the initiation of the motor response. In our search, a total of 7 parameters were identified across 3 studies capturing timing measures related to the timeliness of swallow initiation. These parameters are illustrated in Fig. 3. Swallow initiation was generally slower in the elderly groups as measured by the interval between the bolus entering the pharynx (B1) and the onset of hyoid excursion (G1). However, not all studies reported data supporting this trend: Kang and colleagues [50] found little difference in swallow reaction parameters between their oldest "young" participants and their elderly participants, as did Leonard and colleagues in the measures of the bolus passing or exiting the valleculae [51].

Ref. number	First author	Year	Name of parameter	Grouping onset event	Grouping offset event	Vol (cc)
[36]	Logemann	2000	Pharyngeal delay time	B1	G2	1, 10
[37]	Logemann	2002	Pharyngeal delay time	B1	G2	1, 10
[52]	Kim	2005	Pharyngeal delay time	B1	G2	5
						10
[50]	Kang	2010	Onset of epiglottic deflection	B1	G3	2
[50]	Kang	2010	Onset of supraglottic closure	B1	G4	2
[49]	Mendell	2007	Onset of oral transit	B1	G8	3, 10
[49]	Mendell	2007	Bolus over base of tongue	B1	G8	3, 10
[36]	Logemann	2000	Bolus arrival at upper pyriform sinuses	B5	G8	1, 10
[37]	Logemann	2002	Bolus arrival at upper pyriform sinuses	B5	G8	1, 10

Study key for pharyngeal phase parameters referenced to gesture events.

Ref. number	First author	Year	Name of parameter	Grouping onset event	Grouping offset event	Vol (cc)
[49]	Mendell	2007	Hyoid onset	G1	G8	3, 10
[50]	Kang	2010	Time for hyoid to reach maximal point	G1	G9	2
[50]	Kang	2010	Duration of hyoid excursion	G1	G14	2
[36]	Logemann	2000	Vertical laryngeal movement	G2	G8	1, 10
[37]	Logemann	2002	Vertical laryngeal movement	G2	G8	1, 10
[49]	Mendell	2007	Laryngeal onset	G2	G8	3, 10
[49]	Mendell	2007	First laryngeal vestibule closure	G4	G8	3, 10
[36]	Logemann	2000	Duration of laryngeal vestibule closure	G4	G13	1, 10
[37]	Logemann	2002	Duration of laryngeal vestibule closure	G4	G13	1, 10
[50]	Kang	2010	Duration of supraglottic closure	G4	G13	2
[49]	Mendell	2007	Onset of base of tongue retraction	G5	G8	3, 10
[36]	Logemann	2000	Base of tongue movement	G5	G8	1, 10
[37]	Logemann	2002	Base of tongue movement	G5	G8	1, 10
[36]	Logemann	2000	Base of tongue contact to posterior pharyngeal wall	G6	G11	1, 10
[37]	Logemann	2000	Base of tongue contact to posterior pharyngeal wall	G6	G11	1, 10
[36]	Logemann	2000	Posterior pharyngeal wall movement	G7	G8	1, 10
[37]	Logemann	2002	Posterior pharyngeal wall movement	G7	G8	1, 10
[36]	Logemann	2000	Time to maximum cricopharyngeal opening in relation to first cricopharyngeal opening	G8	G10	1, 10
[37]	Logemann	2002	Time to maximum cricopharyngeal opening in relation to first cricopharyngeal opening	G8	G10	1, 10
[53]	Kern	1999	Total duration of UES opening	G8	G12	5
						10
[36]	Logemann	2000	Cricopharyngeal opening	G8	G12	1, 10
[37]	Logemann	2002	Cricopharyngeal opening	G8	G12	1, 10
[35]	Leonard	2004	Upper esophageal sphincter opening duration	G8	G12	20

The following swallow reaction parameters were reported to have statistically significant differences between the young and old groups: onset of bolus transit (B1 to G1) with a 3 and 20 cc bolus [51], stage transition duration (B1 to G1) with a 5 and 10 cc bolus [52], and bolus at UES (B6 to G1) with a 3 and 20 cc bolus [51]. The study by Leonard and McKenzie [51] referenced the onset of hyoid excursion to five different bolus positions (passing the posterior nasal spine, passing the mandible, reaching the valleculae, passing or exiting the valleculae and arriving at the UES) and for two of these parameters (B1 to G1 and B6 to G1), older participants showed longer response latencies. The

Bolus Transit Parameters

confidence intervals for all other swallow reaction parameters overlap significantly, indicating that there is no clear dissociation by age group.

3.3. Pharyngeal phase parameters referenced to the bolus entering the pharynx

Fig. 4 illustrates the data for six additional pharyngeal phase parameters from 5 studies, in which the onset of a pharyngeal gesture was referenced to the bolus entering the pharynx. Kim and colleagues' measure of pharyngeal delay time (B1 to G2) shows clear dissociation

٥	Young
Δ	Old

Fig. 2. Forest plot of bolus transit parameters.



Fig. 3. Forest plot of swallow reaction parameters.

Young

	Г					2	[[]]	Δ	Old
			$ \longrightarrow $			3 cc, Leonard	[51]*		
			<u>^</u>	,	A	3 cc, Leonard	[51]*		
			$ \longrightarrow $	-		20 cc, Leonar	d [51]*		
				an Kim Ir	'	20 cc, Leonar	d [51]*		
		HQH.		CC, KIM [5.	2]*				
			· 5	cc, Kim [5.	2]*				
		нÇч	1	0 cc, Kim [52]*				
B1 to	G1		<u>⊷</u> ≙⊸ 1	0 cc, Kim [52]*				
		ц.		3 cc, Le	onard [51]				
			_ <u>A</u> '	3 cc, Lee	onard [51]				
			\rightarrow	20 cc, L	eonard [51]				
		-		- 20 cc, L	eonard [51]				
		⊢∽	2 cc, K	ang [50]					
			2 cc, K	ang [50]					
			- 2 cc, K	ang [50]					
	L		2 cc, K	ang [50]					
	Г	$\vdash \frown \vdash$	3 cc, Le	onard [51]					
B2 to	G1	<u>⊢_</u>	→ 3 cc, Le	onard [51]					
D2 10		$\vdash \!\!\! \hookrightarrow \!$	20 cc, l	eonard [51.	L]				
	L	<u>⊢_∆</u>	— 20 cc, l	eonard [51.	L]				
	Г	\mapsto	→ 3 cc, Le	onard [51]					
P2 to	G1	- <u></u>	3 cc, Le	onard [51]					
55 10		\mapsto	20 cc, L	eonard [51.	.]				
	L		20 cc, L	eonard [51	.]				
	Г		÷	3 cc, Leo	nard [51]*				
DC to	C1		· <u></u>	3 cc, Leo	nard [51]*				
B6 (0	GI	, ⊢_()		20 cc, Le	onard [51]*				
	L			20 cc, Le	onard [51]*				
-0.40	-0.20	0.00	0.20	0.40	0.60	0.80	1.00	1.20	1.40
				Time	(sec)				

Swallow Response Parameters

with longer values in the elderly than in the younger group [52]. Epiglottic deflection (B1 to G3) [50] was longer in the younger groups than in the elderly. The only parameter reported to display significant differences between age-groups was pharyngeal delay time (B1 to G2), as measured by both Kim and colleagues and by Logemann and colleagues in their study of men, and in both studies older participants were reported to exhibit a significantly longer pharyngeal delay.

One additional parameter is included in the figure, in which Logemann and colleagues captured the interval between the bolus arriving at the level of the upper pyriform sinuses and the onset of UES opening [36,37]. This parameter was extremely short in both groups; only 0.03 s (95% CI: 0.01–0.07) in the elderly, and ranging from 0.03 s (95% CI: -0.03-0.09) to 0.04 s (95% CI: 0.02-0.06) in the younger groups.

3.4. Pharyngeal phase parameters referenced to gesture events

Fig. 5 displays data from 6 studies for 16 parameters, for which both the onset and offset events are gestures and for which there is no information about bolus location at the time of event indices. These parameters include events related to hvoid movement; larvngeal movement; laryngeal vestibule closure; tongue-base retraction and contact with the posterior pharyngeal wall; and UES opening and closing. There are quite a few parameters that do not vary much between the young and elderly groups. These include: hyoid onset (G1 to G8) [49], time for hyoid to reach maximal point (G1 to G9) [50], duration of hyoid excursion (G1 to G14) [50], vertical laryngeal movement (G2 to G8) [36], laryngeal onset (G2 to G8) [49], first laryngeal vestibule closure (G4 to G8) [49], time to maximum UES opening in relation to first UES opening (G8 to G10) [36,37] and onset of base of tongue retraction (G5 to G8) [49]. Total duration of UES opening (G8 to G12) was found to be significantly different between young and elderly groups with a 10 cc bolus, although both groups

displayed extremely little variability with both the 5 cc and 10 cc boluses [53]. Time to maximum cricopharyngeal opening in relation to first cricopharyngeal opening (G8 to G10) in women as measured by Logemann and colleagues [37] and UES opening duration (G8 to G12) as measured by Leonard and colleagues [35] also showed significantly different timings between the young and elderly groups, with the elderly taking longer for both of the measures.

4. Discussion

After a thorough search of the literature and a strict set of inclusion criteria, 11 studies detailing swallowing timing in the healthy elderly were found, analyzed and synthesized for mean timing measures along with 95% confidence intervals. Results were plotted and examined. While it is obvious that the swallowing mechanism in older adults is different from that of younger adults and ranges for normal elderly swallowing can be extracted, the exact profile of an older adult's swallow cannot be clearly distilled from the articles reviewed. Reasons for differing impressions regarding the profile of an older adult's swallow are discussed.

Conclusions from this review are clearly hampered by the varying measures used to classify the swallow across the 11 studies reviewed. Many of the studies honed in on very specific details of the swallow, but did not provide an impression of how the different aspects of the swallowing mechanism work together as the bolus moves from the oral cavity to the esophagus. As such, one would have to piece together the various studies in order to form a complete picture of swallowing physiology. There were also many studies that reported on the same measures such as transit times, pharyngeal delay and UES opening duration. However, there were some discrepancies seen between results. As mentioned in Molfenter and Steele's [40] study on temporal variability, differing definitions could play a role in these discrepancies. The definition of "healthy" participants can also vary across studies. In

Pharyngeal Phase Events Indexed to Bolus Entry into the Pharynx

	r.		◇ Young
	→→→ 1 & 10 cc, Logemann [36]*	l	∆ Old
	→ 1 & 10 cc, Logemann [36]*		
	⊢⊘⊣ 1 & 10 cc, Logemann [37]		
B1 to G2	△ 1 & 10 cc, Logemann [37]		
0110 01	→ 5 cc, Kim [52]*		
	→ 5 cc, Kim [52]*		
	+⊘- 10 cc, Kim [52]*		
	+ <u>≜</u> + 10 cc, Kim [52]*		
	2 cc, Kang [50]		
P1 to C2	2 cc, Kang [50]		
B1 (0 G5	→→→ 2 cc, Kang [50]		
	2 cc, Kang [50]		
	└────────────────────────────────────		
B1 to G4	2 cc, Kang [50]		
B1 (0 04	→→→ 2 cc, Kang [50]		
	2 cc, Kang [50]		
		3 & 10 cc,	Mendell [49]
		3 & 10 cc,	Mendell [49]
		3 & 10 cc,	Mendell [49]
		3 & 10 cc,	Mendell [49]
B1 to G8	2.8.10 cc Mandall [40]	⊣ 3 & 10 cc,	wendeli [49]
	3 & 10 cc, Mendell [49]		
	3 & 10 cc, Mendell [49]		
	3 & 10 cc, Mendell [49]		
	3 & 10 cc, Mendell [49]		
	$[\qquad \qquad$		
	1 & 10 cc, Logemann [36]		
B5 to G8	1 & 10 cc, Logemann [37]		
	⊢ 1 & 10 cc, Logemann [37]		
-1	0.20 0.00 0.20 0.40 0.60 0.80	1.00	1.20
	time local		

some of the studies in this review, "healthy" was not clearly defined and included participants that did not have history of dysphagia and were also free from disease known to influence swallowing. In other studies it was simply stated that subjects were "healthy" or "normal", and this was not elaborated upon. It was left up to the reader to interpret what these terms might or might not encompass.

Slight variations in definitions for a single measure can also contribute to differences in results. These differences become evident in Table 4. For example, Dejaeger and colleagues [44] defined the onset of oropharyngeal transit as the arrival of the bolus head at the tongue base, whereas Kendall and colleagues [34] defined the onset as the head of the bolus passing the nasal spine. The offsets of both definitions also varied: Dejaeger and colleagues marked the offset as the moment when the bolus arrived at the entrance of the larynx while Kendall and colleagues mark the offset as the moment when the bolus arrives in the valleculae. It is clear that such variations in definitions may cause differences across the measures reported in different studies. In grouping the studies for this review it also quickly became evident that many scientists are studying similar parameters, but with slightly different names and definitions. For example, Kim et al. [52] and Leonard and McKenzie [51] both studied stage transition duration; Kim called this parameter by its name whereas Leonard used the term "onset of bolus transit". A naïve reader may have mistaken the two parameters to be very different measures had they not looked carefully at the definitions. The lack of standardization in definitions and naming conventions across the literature complicates the ability to compare measures from one study to another. To combat this, we clustered different terms with similar definitions together.

Other sources of variation in timing measures could be due to a large array of factors such as sample size, male to female ratio, and exact age range of the elderly sample. Sample sizes for elderly participants ranged from 8 [36,37] to 63 [34]. In three studies, the sample size was reported as 23, and it has been confirmed that all three of these articles reported data for the same sample [34,35,51,54]. However, the results for some parameters differed slightly from one study to another. The ratio of males to females also differed across the studies reviewed. One study solely reported data for elderly women and did not include any men in the sample [37]. Another study only included men in the sample, and did not report on any women [36].

It is well-known that variability tends to decrease with increases in sample size, so the variability seen for some measures may be due to the relatively small sample sizes studied. This is untrue for a few select parameters, such as bolus past the mandible (B1 to G1) as measured by Leonard and McKenzie [51]. Leonard had a relatively large sample size but this measure still suffered from great variability. In other cases, such as onset of vertical laryngeal movement (G2 to G8) as studied by Logemann and colleagues [37], variability differed substantially between young and old participants of the same sample size. Logemann's finding that older adults present with significantly longer pharyngeal delays [36] is also surprising considering the large variability present in the measures from the older group and the overlapping confidence intervals, as shown in Fig. 4. In these cases, one can only assume that the elderly have a larger range of normal variation.

The definition of "older adults" or "elderly adults" also appeared to differ across studies. There were two studies that considered older adults to be aged 60 or older [45,49], yet there were four studies that used a cutoff of 65 or older to classify elderly adults [34,35,50,51]. An additional two studies considered older adults to be aged 70 or older [52,53], and two studies reported on a sample that were aged 80 or older [36]. One study did not report the minimum age of the older

Fig. 4. Forest plot of pharyngeal phase events indexed to bolus entry into the pharynx.



Fig. 5. Forest plot of hyoid and larynx pharyngeal phase events indexed to gestures.

participants [44]. Across the seven studies that reported the mean age of their older participants, mean age was 70 years or older [35,44,45,49–51,53]. Four of these studies reported a mean age of the elderly sample as 75 years old or greater. Given that the literature is quite clear that as we age we naturally become increasingly frail, studies with older samples may be biased toward greater apparent levels of impairment. The differences in age across the studies included in this review hampers our ability to draw firm conclusions regarding the changes in swallowing that are associated with particular age groups. For example, when comparing studies with a relatively young older healthy sample [45,49] to a study with a relatively old older healthy sample [36], we found that the onset of superior laryngeal movement to onset of UES opening (G2 to G8) was longer in the relatively younger samples, compared to the relatively older samples. In contrast, the onset of tongue base retraction to the onset of UES opening (G5 to G8) was longer in the relatively older samples compared to the relatively vounger samples. If all studies examined only the very old (i.e. those over the age of 80) we might see more significant differences in swallowing timing between the old and young. Since age is a continuum and the consequences of aging are gradual, it is difficult to predict if/when an elderly swallow might start to differ significantly from a younger swallow, based on the research currently available.

Another aspect to consider is videofluoroscopy procedure. This method of swallowing evaluation is often described as a gold standard, yet many aspects of the procedure may differ across studies. Frame rates can differ across studies, as can the stimuli being used and the number of swallows elicited for each stimulus. Differing frame rates, such as 15 versus 30 frames/s, have been shown to affect judgments regarding swallowing impairment [55]. Barium stimuli can differ both

by brand and across barium concentrations and any resulting differences in viscosity could influence swallowing behavior. In the 11 studies included in this review, Dejaeger, as well as Logemann's group, which includes the study performed by Mendell, simply stated that liquid barium was used in the study; no additional details were given [36,37,44,49]. Im and colleagues provided slightly more detail; they used thin liquid reported to have a viscosity of 14 mPas, although the shear rate at which this measurement was obtained was not reported [45]. Kang reported using a 35% w/v diluted barium solution created with Solutop Suspension [50]. Kendall and Leonard both used liquid barium that was a 60% w/v concentration, made with Barosperse Barium Sulfate Suspension: the reported viscosity of this barium was 35 mPa s at 40 reciprocal seconds, as measured with a #4 Ford Cup [34,35,51]. Kern and Zamir both used similar products; Kern and colleagues used liquid barium boluses made with EZ-HD (viscosity 300 cP) [53]. Kim and colleagues did not give quite as much detail; they reported using a 50/50 mixture of water and E-Z-HD Barium Sulfate Powder for Suspension to create thin liquid boluses [52]. Even if the type of stimulus and viscosity is held constant, the volume and number of stimuli presented to the participants may differ across studies. In this review, studies used 1 cc [34,36,37,52], 2 cc [50], 3 cc [49,51], 5 cc [45,52], 10 cc [36,37,44,49,52], and 20 cc boluses [34,35,51], or a combination of any of the volumes listed. Previous research by Nascimento and colleagues studied the effects of bolus volume on swallow event duration in healthy subjects [56]. They timed the following events: onset of propulsive tongue tip movement at the maxillary incisors, onset and end of the hyoid movement, passage of the bolus head through the fauces, passage of the bolus tail through the fauces, and onset and offset of upper esophageal sphincter (UES) opening. Of these five events, only duration of UES opening was found to increase with larger volumes. Similarly, another study by Molfenter and Steele found that bolus volume significantly impacted UES opening duration, laryngeal closure duration, the laryngeal closure-to-UES opening interval, and the pharyngeal transit time interval, but not hvoid movement duration or the stage transition duration interval [57]. Given these findings, it is clear that findings of the current review would differ had all studies used the same VFSS protocol.

Another source of variation pointed out by another study by Molfenter and Steele [40] is the use of swallow cueing. Uncued swallows are generally initiated with the bolus head at a more posterior location the oropharynx, consequently resulting in longer timing measures [58,59]. The majority of the studies included in this review were not transparent with regard to their use of cueing. Each of these factors alone, or in combination, could influence the results of a study and contribute to variations in similar or identical measurements across studies.

5. Limitations

This review looked for peer-reviewed articles in the literature describing swallow timing measures in elderly, healthy adults. However, as in any review, the results are limited to articles that were found based on the specific search strategy of looking for key words and MeSH headings. It is possible that additional articles might have been sourced using alternative search criteria, such as title or abstract terms. The inclusion criteria further limited the search results to studies that reported swallow timing data for elderly, healthy adults in a way that allowed for a detailed analysis and creation of forest plots. The majority of articles that were considered lacked the necessary information for inclusion. Finally, only 45% of the articles considered in the review process underwent duplicate review for inclusion. It is possible that the decisions made based on review by only one rater might have excluded some articles that a second rater might have judged eligible, or vice versa.

Pharyngeal Phase Events Indexed to Gestures Part 2: Base of Tongue and Upper Esophageal Sphincter

67 to 69	→→→ 1 & 10 cc, Logemann [36] →→→→ 1 & 10 cc, Logemann [36]								
67 10 68	→→ 1 & 10 cc, Logemann [37] → ▲ 1 & 10 cc, Logemann [37]								
CR 40 C10	 ☆ 1 & 10 cc, Logemann [36] ☆ 1 & 10 cc, Logemann [36] 								
G8 to G10	☆ 1 & 10 cc, Logemann [37]* → 1 & 10 cc, Logemann [37]*								
[∑ 5 cc, Kern [53]								
	 ✓ a 5 cc, Kern [53] ◇ 10 cc, Kern [53]* ▲ 10 cc, Kern [53]* 								
68 to 612	 ↓ 5 cc, Kern [53] ↓ 10 cc, Kern [53]* ▲ 10 cc, Kern [53]* ↓ 1 & 10 cc, Logemann [36] ↓ 1 & 10 cc, Logemann [36] 								
G8 to G12	 → 1 & 10 cc, Logemann [36] →→ 1 & 10 cc, Logemann [36] →→→ 1 & 10 cc, Logemann [37] 								
G8 to G12	 ↓ 5 cc, Kern [53] ▲ 5 cc, Kern [53] ◇ 10 cc, Kern [53]* ▲ 10 cc, Kern [53]* → ↓ 1 & 10 cc, Logemann [36] → ↓ 1 & 10 cc, Logemann [36] → ↓ 1 & 10 cc, Logemann [37] → ↓ 1 & 10 cc, Logemann [37] 								
G8 to G12	 → 5 cc, Kern [53] ▲ 5 cc, Kern [53] ◇ 10 cc, Kern [53]* ▲ 10 cc, Kern [53]* →→ 1 & 10 cc, Logemann [36] →→→ 1 & 10 cc, Logemann [37] →→→ 1 & 20 cc, Leonard [35]* 								

6. Conclusion

This review of the literature and detailed analysis regarding timing measures of swallowing in healthy, elderly adults across several studies shows that the swallow of an elderly, healthy adult differs from that of a younger, healthy adult. Current clinical decisions are often based on the comparison of an elderly patient to a younger, healthy adult, which may cause both clinicians and researchers to conclude, incorrectly, that an older individual has dysphagia. Based on the analysis performed in this review the following conclusions can be drawn:

- It appears that the natural process of aging affects a few very specific timing parameters. Most notably the following parameters are consistently reported across studies to be different in the elderly compared to their younger counterparts:
 - 1. **Swallow reaction parameters** between the bolus entering the pharynx and onset of hyoid excursion (B1 to G1) are longer in the elderly.
 - 2. Pharyngeal delay times (B1 to G2) are longer in the elderly.
 - 3. Total duration of UES opening (G8 to G12) is longer in the elderly.

- 4. The interval between bolus entry into the pharynx and epiglottic deflection (B1 to G3) was reported in a single study to be shorter in the elderly than in younger participants.
- Clinicians and researchers should be aware that many swallow timing parameters appear to be unaffected by aging. Apart from the parameters mentioned above, large deviations from the norms, even when such norms are based on a young sample, are considered likely to be indicators of dysphagia rather than presbyphagia in the elderly.
- Bolus transit parameters do not appear to change much as a function of age.

Clinicians and researchers can use the figures in this review as guidelines for normal swallow timing. This can be done by comparing timing measures of their disordered patients and participants to the lowest lower confidence interval and highest upper confidence interval for each parameter, and determining if their subject falls within or outside of the range. Numbers outside of the range should be considered disordered. Future research should focus on standardization of videofluoroscopy swallowing study protocols and of the definition of "elderly" so that appropriate references can be established for healthy older adults.

Appendix A

Table A.1

Descriptive statistics for bolus transit parameters.

Onset-offset	First author	Year	Group	Vol (cc)	Mean (s)	Std dev	LCI	UCI
I1 to B1	Dejaeger	1994	Young	10	0.50	0.30	0.37	0.63
			Old	10	1.70	1.70	0.87	2.53
B1 to B2	Kendall	2004	Old	1	0.38	0.24	0.28	0.48
			Old	20	0.39	0.18	0.32	0.46
B1 to B3	Mendell	2007	Young	3, 10	0.09	0.15	0.02	0.15
			Young	3, 10	0.13	0.16	0.07	0.20
			Old	3, 10	0.13	0.16	0.06	0.20
			Old	3, 10	0.13	0.16	0.06	0.20
			Old	3, 10	0.25	0.15	0.18	0.31
B1 to B4	Dejaeger	1994	Young	10	0.55	0.11	0.50	0.60
			Old	10	0.59	0.18	0.50	0.68
B1 to B6	Im	2012	Young	5	0.70	0.14	0.64	0.76
			Old	5	0.80	0.13	0.74	0.86
B1 to B7	Kendall	2004	Old	1	1.11	0.40	0.95	1.27
			Old	20	1.19	0.20	1.11	1.27
	Dejaeger	1994	Young	10	0.90	0.12	0.85	0.95
			Old	10	0.91	0.26	0.78	1.04
B2 to B7	Kendall	2004	Old	1	0.64	0.19	0.56	0.72
			Old	20	0.77	0.13	0.72	0.82
	Leonard	2004	Young	20	0.64	0.20	0.60	0.68
			Old	20	0.86	0.42	0.77	0.95
B4 to B7	Dejaeger	1994	Young	10	0.79	0.18	0.71	0.87
			Old	10	0.76	0.21	0.66	0.86

Table A.2

Descriptive statistics fo	or swallow	reaction	parameters.
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Onset-offset	First author	Year	Group	Vol (cc)	Mean (s)	Std dev	LCI	UCI
B1 to G1	Leonard	2006	Young	3	0.21	0.26	0.15	0.27
			Old	3	0.53	0.64	0.40	0.66
			Young	20	0.25	0.32	0.17	0.33
			Old	20	0.54	0.69	0.40	0.68
	Kim	2005	Young	5	0.06	0.07	0.03	0.09
			Old	5	0.20	0.06	0.17	0.23
			Young	10	0.08	0.07	0.05	0.11
			Old	10	0.23	0.07	0.20	0.26
	Leonard	2006	Young	3	0.04	0.20	-0.01	0.09
			Old	3	0.17	0.48	0.07	0.27
			Young	20	0.15	0.35	0.06	0.24
			Old	20	0.21	0.58	0.09	0.33
	Kang	2010	Young	2	0.02	0.13	- 0.04	0.08
			Young	2	0.01	0.17	-0.06	0.08
			Young	2	0.03	0.20	-0.07	0.13
			Old	2	0.03	0.14	- 0.04	0.10
B2 to G1	Leonard	2006	Young	3	0.03	0.19	-0.02	0.08
			Old	3	0.06	0.37	-0.02	0.14
			Young	20	0.04	0.16	0.00	0.08
			Old	20	0.06	0.44	-0.03	0.15
B3 to G1	Leonard	2006	Young	3	0.10	0.14	0.07	0.13
			Old	3	0.08	0.16	0.05	0.11
			Young	20	0.06	0.26	0.00	0.12
			Old	20	0.07	0.39	-0.01	0.15
B6 to G1	Leonard	2006	Young	3	0.26	0.12	0.23	0.29
			Old	3	0.28	0.09	0.26	0.30
			Young	20	0.11	0.26	0.05	0.17
			Old	20	0.21	0.14	0.18	0.24

Table A.3				
Descriptive statistics for pharyngea	l phase parameters	referenced to th	e bolus entering	the pharynx.

Onset-offset	First author	Year	Group	Vol (cc)	Mean (s)	Std dev	LCI	UCI
B1 to G2	Logemann	2000	Young	1.10	0.15	0.08	0.09	0.21
	0		Old	1, 10	0.06	0.20	-0.08	0.20
		2002	Young	1, 10	0.11	0.06	0.07	0.15
			Old	1, 10	0.11	0.28	- 0.09	0.31
	Kim	2005	Young	5	0.10	0.05	0.08	0.12
			Old	5	0.17	0.05	0.15	0.19
			Young	10	0.10	0.06	0.07	0.13
			Old	10	0.19	0.05	0.17	0.21
B1 to G3	Kang	2010	Young	2	0.11	0.15	0.04	0.18
	Ū.		Young	2	0.13	0.23	0.03	0.23
			Young	2	0.19	0.18	0.10	0.28
			Old	2	0.01	0.14	- 0.06	0.08
B1 to G4	Kang	2010	Young	2	0.43	0.18	0.34	0.52
			Young	2	0.35	0.22	0.26	0.44
			Young	2	0.43	0.18	0.34	0.52
			Old	2	0.37	0.12	0.31	0.43
B1 to G8	Mendell	2007	Young	3, 10	0.48	0.34	0.33	0.62
			Young	3, 10	0.67	0.33	0.53	0.81
			Old	3, 10	0.72	0.33	0.58	0.87
			Old	3, 10	0.60	0.33	0.45	0.74
			Old	3, 10	0.82	0.32	0.68	0.96
			Young	3, 10	0.17	0.21	0.08	0.26
			Young	3, 10	0.24	0.21	0.15	0.33
			Old	3, 10	0.27	0.21	0.17	0.36
			Old	3, 10	0.23	0.21	0.14	0.32
			Old	3, 10	0.37	0.21	0.28	0.46
B5 to G8	Logemann	2000	Young	1, 10	0.03	0.08	- 0.03	0.09
			Old	1, 10	0.03	0.03	0.01	0.05
		2002	Young	1, 11	0.04	0.03	0.02	0.06
			Old	1, 10	0.03	0.06	-0.01	0.07

Table A.4 Descriptive statistics for pharyngeal phase parameters referenced to gesture events.

Onset-offset	First author	Year	Group	Vol (cc)	Mean (s)	Std dev	LCI	UCI
G1 to G8	Mendell	2007	Young	3, 10	0.23	0.04	0.21	0.25
			Young	3, 10	0.26	0.04	0.24	0.28
			Old	3, 10	0.28	0.04	0.26	0.30
			Old	3, 10	0.30	0.04	0.28	0.31
			Old	3, 10	0.25	0.04	0.23	0.27
G1 to G9	Kang	2010	Young	2	0.43	0.14	0.36	0.50
			Young	2	0.43	0.26	0.32	0.54
			Young	2	0.48	0.16	0.40	0.56
			Old	2	0.45	0.17	0.37	0.53
G1 to G14	Kang	2010	Young	2	1.03	0.27	0.90	1.16
			Young	2	1.02	0.23	0.92	1.12
			Young	2	1.05	0.15	0.98	1.12
			Old	2	1.02	0.24	0.90	1.14
G2 to G8	Logemann	2000	Young	1, 10	0.02	0.06	-0.02	0.06
			Old	1, 10	0.02	0.06	-0.02	0.06
		2002	Young	1, 10	0.08	0.03	0.06	0.10
			Old	1, 10	0.16	0.17	0.04	0.28
	Mendell	2007	Young	3, 10	0.24	0.04	0.22	0.25
			Young	3, 10	0.25	0.04	0.23	0.27
			Old	3, 10	0.29	0.04	0.27	0.31
			Old	3, 10	0.29	0.04	0.27	0.31

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			Old	3, 10	0.25	0.04	0.23	0.27
G4 to G8	Mendell	2007	Young	3, 10	0.02	0.04	0.00	0.03
			Young	3, 10	0.00	0.04	- 0.01	0.02
			Old	3, 10	0.01	0.04	0.00	0.03
			Old	3, 10	0.02	0.04	0.00	0.03
			Old	3, 10	0.01	0.04	0.00	0.03
G4 to G13	Logemann	2000	Young	1, 10	0.51	0.11	0.43	0.59
	0		Old	1, 10	0.56	0.11	0.48	0.64
		2002	Young	1, 10	0.58	0.08	0.52	0.64
			Old	1, 10	0.71	0.20	0.57	0.85
	Kang	2010	Young	2	0.31	0.11	0.26	0.36
	-		Young	2	0.38	0.19	0.30	0.46
			Young	2	0.33	0.21	0.23	0.43
			Old	2	0.50	0.20	0.40	0.60
G5 to G8	Mendell	2007	Young	3, 10	0.01	0.04	-0.01	0.02
			Young	3, 10	0.04	0.04	0.02	0.06
			Old	3, 10	0.01	0.04	- 0.01	0.02
			Old	3, 10	0.02	0.04	0.00	0.03
			Old	3, 10	0.04	0.04	0.02	0.05
	Logemann	2000	Young	1, 10	0.15	0.08	0.09	0.21
			Old	1, 10	0.19	0.14	0.09	0.29
		2002	Young	1, 10	0.05	0.08	- 0.01	0.11
			Old	1, 10	0.09	0.25	- 0.09	0.27
G6 to G11	Logemann	2000	Young	1, 10	0.31	0.14	0.21	0.41
			Old	1, 10	0.40	0.08	0.34	0.46
		2002	Young	1, 10	0.40	0.20	0.26	0.54
			Old	1, 10	0.44	0.28	0.24	0.64
G7 to G8	Logemann	2000	Young	1, 10	0.12	0.08	0.06	0.18
			Old	1, 10	0.23	0.11	0.15	0.31
		2002	Young	1, 10	0.11	0.06	0.07	0.15
			Old	1, 10	0.10	0.20	- 0.04	0.24
G8 to G10	Logemann	2000	Young	1, 10	0.14	0.03	0.12	0.16
			Old	1, 10	0.13	0.03	0.11	0.15
		2002	Young	1, 10	0.13	0.03	0.11	0.15
			Old	1, 10	0.14	0.06	0.10	0.18
G8 to G12	Kern	1999	Young	5	0.57	0.01	0.57	0.58
			Old	5	0.61	0.01	0.61	0.62
			Young	10	0.61	0.01	0.61	0.62
			Old	10	0.63	0.01	0.63	0.64
	Logemann	2000	Young	1, 10	0.42	0.06	0.38	0.46
			Old	1, 10	0.43	0.06	0.39	0.47
		2002	Young	1, 10	0.41	0.06	0.37	0.45
			Old	1, 10	0.48	0.06	0.44	0.52
	Leonard	2004	Young	20	0.50	0.11	0.48	0.52
			Old	20	0.66	0.12	0.63	0.69

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