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Normative Reference Values for FEES and VASES: Preliminary Data From 39 Nondysphagic, Community-Dwelling Adults

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ABSTRACT

Purpose: The aim of this study was to establish preliminary reference values for the Visual Analysis of Swallowing Efficiency and Safety (VASES)—a standardized rating methodology used to evaluate swallowing safety and efficiency for flexible endoscopic evaluation of swallowing (FEES).
Method: FEES were completed in nondysphagic, community-dwelling adults using a standardized protocol of 15 swallowing trials that varied by bolus size, consistency, contrast agent, and swallowing instructions. FEES were blindly analyzed using VASES. Primary outcome measures included bolus location at swallow onset, Penetration–Aspiration Scale (PAS) scores, and percentage-based residue ratings for six anatomic landmarks. Secondary outcome measures included sip size, bite size, and number of swallows.
Results: Thirty-nine healthy adults completed the study, yielding an analysis of 584 swallows. Swallows were initiated with the bolus in the pharynx for 41.8% of trials. PAS 1 was the most common score, accounting for 75.3% of trials, followed by PAS 3, which accounted for 18.8% of trials. When residue was present (> 0%), the amount was relatively small across all anatomic landmarks, with median residue ratings of 2.0% (oropharynx), 1.5% (hypopharynx), 3.0% (epiglottis), 3.0% (laryngeal vestibule), and 3.5% (vocal folds). Five events of aspiration were observed, which were characterized by subglottic residue ratings of 1%, 3%, 10%, 24%, and 90%. The average sip size of self-selected volume cup sips of water was 19.8 ml, and the average bite size of a 3.0-g saltine cracker was 1.33 g. Moreover, 78% of the trials in this study protocol (except 90-ml trials) were completed in a single swallow.
Discussion: The results from this study provide preliminary norms for VASES that could be used as a reference when assessing functional swallowing outcomes during FEES. While this is an important first step in establishing norms for FEES and VASES, clinicians and researchers should be mindful that the normative reference values from this study are from a relatively small study sample (N = 39), with most people below the age of 60 years (n = 30). Future research should expand on these norms by including a greater number of people across the age continuum and with greater racial, ethnic, and gender diversity.
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Flexible endoscopic evaluation of swallowing (FEES) is a safe and effective instrumental procedure used by speech-language pathologists, physicians, and researchers to aid in the comprehensive assessment of swallowing (Kasle et al., 2020; Langmore et al., 1988; Nacci et al., 2022). Current evidence demonstrates that one of the primary diagnostic advantages of FEES is its ability to aid in the sensitive and reliable assessment of functional (bolus-related) swallowing outcomes (Giraldo-Cadavid et al., 2017). Specifically, FEES facilitates visualization of pharyngeal residue (da Silva et al., 2010; Kelly et al., 2006; Park et al., 2015; Pisegna & Langmore, 2016; Rao et al., 2003; Scharitzer et al., 2019) and airway invasion (penetration and aspiration; Armstrong et al., 2019; da Silva et al., 2010; Kamity et al., 2020; Kelly et al., 2007; Park et al., 2015; Rao et al., 2003) with greater frequency and severity than videofluoroscopic swallowing studies.

One validated method used to rate functional swallowing outcomes during FEES is the Visual Analysis of Swallowing Efficiency and Safety (VASES; Curtis, Borders, Perry, et al., 2022; Curtis, Borders, & Troche, 2022). VASES was developed to increase the transparency and standardization of FEES by establishing clearly defined anatomic and temporal boundaries for rating swallowing outcomes. Furthermore, continuous percentage-based rating scales, as opposed to categorical rating scales, were integrated into VASES in light of research demonstrating their heightened sensitivity, reliability, and validity for residue analysis during FEES (Pisegna et al., 2020; Pisegna, Borders, et al., 2018; Pisegna, Kaneoka, et al., 2018).

While validity (Curtis, Borders, & Troche, 2022) and reliability (Curtis, Borders, Perry, et al., 2022) of VASES have been previously established, normative data are currently lacking. Normative data are frequently used by clinicians and researchers to facilitate comparisons between a patient's performance and a desired reference group (e.g., healthy adults). For FEES, comparing a patient's VASES findings to normative reference values can aid clinicians and researchers in estimating how abnormal a person's swallow function is compared to nondysphagic individuals. Estimating the degree to which a person's swallow function is abnormal ultimately assists in diagnosing the presence of a swallowing impairment and the need for airway protective interventions.

Some normative data have been previously reported for healthy adult swallows during FEES, though several noteworthy limitations are present. First, most normative data for FEES focus primarily on ratings of the Penetration–Aspiration Scale (PAS; Rosenbek et al., 1996), without detailed descriptions of the anatomic boundaries and temporal phases used to guide such ratings (Butler et al., 2018; Butler, Stuart, & Kemp, 2009; Butler, Stuart, Markley, & Rees, 2009). If the anatomic and temporal boundaries used by clinicians and researchers do not match with the unreported boundaries used in the previous normative studies, then the interpretation of a person's FEES as it relates to healthy norms may not be valid. Second, normative data for FEES describing the amount of residue in the larynx and subglottis are lacking. Providing visuoperceptual estimations of the amount of laryngeal and subglottic residue is important to provide a more holistic description of swallowing safety impairments above and beyond PAS alone. For example, a person with aspirate residue covering 6% of the subglottis may likely be managed very differently from a person with aspirate residue covering 60% of the subglottis. Third, while pharyngeal residue has been previously described for healthy adults during FEES (Aviv et al., 1998; Badenduck et al., 2014; Butler, Stuart, & Kemp, 2009; de Lima Alvarenga, Abrahão, et al., 2018; de Lima Alvarenga, Dall'Oglio, et al., 2018; Kamarunas et al., 2014), none of these previous healthy adult studies used validated pharyngeal residue rating scales, nor did they use scales that used continuous (as opposed to categorical) rating methods. This is important since continuous pharyngeal residue rating methods have been found to enhance FEES assessment sensitivity and reliability (Pisegna et al., 2020; Pisegna, Borders, et al., 2018; Pisegna, Kaneoka, et al., 2018). Lastly, to the authors' knowledge, no normative data exist that describe sip size, bite size, and number of swallows during FEES. Information about sip size, bite size, and number of swallows is important because it provides context for interpreting pharyngeal residue, penetration, and aspiration during FEES. For example, a clinician may interpret liquid residue filling the valleculae 20% as less severe if that amount of residue was present after one swallow compared to three swallows, or if that same amount of residue was present after a 25-ml sip compared to a 5-ml sip.

Given the frequent and growing use of FEES in clinical and research practices (Kasle et al., 2020), there is a critical need to develop large and robust normative data sets for rating scales used to interpret FEES. Normative data should be developed for specific swallowing conditions using transparent rating methodologies. Given that normative data are currently lacking for VASES, the aim of this descriptive study was to establish preliminary normative reference values for VASES functional swallowing outcome measures, in addition to typical sip sizes, bite sizes, and number of swallows, across a range of standardized swallowing conditions using convenience sampling of nondysphagic, community-dwelling, healthy adults.

Method

Research Design

This was a prospective, observational study of nondysphagic, community-dwelling adults who underwent a standardized FEES protocol at an academic clinical research laboratory. All procedures were performed in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Approval was obtained from the institutional review board (IRB 21-392). Informed consent was obtained from all participants prior to enrollment in this research study.

Participants

Nondysphagic, community-dwelling adults were included for study participation if reporting no previous or current history of swallowing problems when asked during an initial telephone screening: "Do you have any perceived swallowing difficulties or known swallowing problems?" Participants were excluded if reporting swallowing difficulties or a current or previous history of any of the following: gastroesophageal, respiratory, or neurological diseases; head and neck cancer; surgeries of the head, neck, or spine (other than routine dental surgery, tonsillectomy, or adenoidectomy); or dietary alteration due to feeding or swallowing difficulties. Participants were recruited using a variety of online and in-person resources, including Craigslist, Twitter, Facebook, Instagram, paper flyers, and word of mouth. Participants were blinded to the aims of this study. Recruitment and data collection occurred from December 2021 to August 2022. Given that our aims were descriptive in nature and did not involve inferential statistics, we recruited a convenience sample of 39 participants to begin to establish a normative database in healthy adults. A convenience sample of 39 participants was set as the recruitment target to match the sample size of recently published reference values for videofluoroscopy (Steele et al., 2019) for potential comparisons of functional swallowing outcomes.

FEES Equipment and Procedure

Once enrolled, participants underwent a standardized FEES protocol, which typically lasted an average of 12 min. The FEES was performed with participants seated comfortably in an upright position. FEES equipment consisted of a 3.0-mm diameter flexible distal chip laryngoscope (ENT-5000, Cogentix Medical) and video system with integrated LED light source LCD display (DPU-7000A, Cogentix Medical). Equipment was white-balanced prior to the start of every FEES. No topical anesthetics or vasoconstrictors were administered during the FEES. Water was used to lubricate the body and distal end of the laryngoscope, and an alcohol wipe was used to wipe off any excess water on the camera lens prior to insertion.

All FEES were completed by the first author, a speech-language pathologist, and a board-certified specialist in swallowing with 9 years of experience performing and interpreting FEES, as well as a graduate speech-language pathology intern. The first author was the endoscopist for all FEES, and the graduate interns assisted with delivery food and drinks to the participants and with weighing the foods and liquids before and after consumption.

The tip of the laryngoscope was positioned within the mid-to-low nasopharynx between the superior aspect of the soft palate and posterior pharyngeal wall before and during all swallows to reduce the risk of bolus adhesion to the camera lens (i.e., in the "high" position). The scope remained in this position after the swallow to assess patterns of pharyngeal residue, penetration, and aspiration. The scope was advanced further into the laryngeal vestibule after 5 s of rest breathing only when airway invasion was suspected but when residue patterns could not be confidently distinguished from vascularity, shadows, or secretions.

Participants were asked to avoid talking throughout the entire FEES unless instructed by the endoscopist or when needing to express concern or physical discomfort. Approximately 5 s of rest breathing was elicited after the swallow before participants were instructed by the endoscopist to say /i/ or before the scope was advanced into the oropharynx and laryngeal vestibule. Sips of clear water were provided between swallowing trials as needed to clear any bolus adhesion on the camera lens and to reduce the amount of residue, which may have been present from previous swallowing trials.

Bolus Preparation

Room temperature water, pudding, and saltine crackers were used for the swallowing protocol. White (AmeriColor), blue (Chef-o-Van), and green (Chef-o-Van) food dyes were used as contrast agents to enhance endoscopic visualization of the ingested foods and liquids (Curtis et al., 2020). As outlined in the below protocol, all liquid trials (except 90 ml) were repeated twice. The first of the two liquid trials within each water swallowing condition was a heavily concentrated, white-dyed water with maximal coating effect, prepared to a ratio of 144 ml of water with 6 ml

of white food coloring. The second of the two liquid trials within each water swallowing condition was a green opaque water with minimal to no coating effect, prepared to a ratio of 148 ml of water with 1 ml of white food coloring and 1 ml of green food coloring. Five, 10, and 20 ml of the colored water were then removed from each of the 150-ml water cups using a 10-ml syringe and placed into separate 30-ml medicine cups.

The 90-ml uninterrupted water swallowing trial was a heavily concentrated, white-dyed water with maximal coating effect prepared using 4 ml of white dye added to 86 ml of water. All liquids were mixed prior to the start of the exam until a homogenous mixture was observed. Liquids were remixed immediately prior to bolus administration to ensure the desired coating effect would be achieved during swallowing. The vanilla pudding was prepared as a blue opaque pudding (3.25-oz cup of pudding mixed with 1 ml of blue dye).

International Dysphagia Diet Standardisation Initiative (IDDSI) testing methods were used to measure the consistency of the boluses in this study after mixing with contrast agents. Water was measured to be IDDSI Level 0, vanilla pudding was measured to be IDDSI Level 4, and the saltine cracker was IDDSI 7.

Swallowing Protocol

A standardized protocol of 15 swallowing trials across eight swallowing conditions were presented in a fixed order to all participants (see Table 1). All boluses were self-administered, nonheld, and noncued. The first swallowing condition was a "natural" swallowing condition, whereby participants were not instructed to complete the trials in a certain number of swallows. All other swallowing conditions were completed using a "single-swallow" instruction, whereby participants were asked to complete each trial in one swallow as best as able and to "wait at least 5 seconds before doing a second or third swallow if needed." This was done to improve ease of VASES interpretation, reduce the frequency of piecemeal deglutition, and control for bolus volume during the swallow. The verbal swallowing instructions outlined in Table 1 were given prior to the start of each new swallowing condition so as to avoid any effects of verbal cueing (Curtis & Troche, 2020) or bolus holding (Curtis et al., 2021) during the actual swallow.

VASES Outcomes

VASES uses a percentage-based rating method, transparent anatomic structures, and transparent temporal boundaries to facilitate standardized ratings of swallowing safety and efficiency during FEES. The four temporal boundaries for VASES included (a) before the swallow, (b) during the swallow, (c) after the swallow, and (d) between bolus trials. The six anatomic structures included the oropharynx, hypopharynx, epiglottis, laryngeal vestibule, vocal folds, and subglottis. Using these anatomic structures and temporal boundaries, the following VASES outcomes were measured for each swallowing trial: (a) bolus location at swallow onset, (b) presence and amount of residue for each anatomic structure, and (c) PAS scores (Rosenbek et al., 1996).

Bolus Location at Swallow Onset

Bolus location at swallow onset was rated by first identifying the onset of the "during the swallow" phase, as

Table 1. Standardized flexible endoscopic evaluations of swallowing protocol.

Order of presentation	Swallow condition	Verbal instruction	No. of trials
1	Self-selected volume of water, via 8-oz cup, natural swallow	"Take one normal size sip, whatever is normal for you, and drink it like you normally would."	2
2	5 ml of water, via 30-ml medicine cup, single swallow	"Put all of this in your mouth and try to swallow it in just one swallow."	2
3	10 ml of water, via 30-ml medicine cup, single swallow	"Put all of this in your mouth and try to swallow it in just one swallow."	2
4	20 ml of water, via 30-ml medicine cup, single swallow	"Put all of this in your mouth and try to swallow it in just one swallow."	2
5	Self-selected volume of water, via 8-oz cup, single swallow	"Take one normal size sip, whatever is normal for you, and swallow it in just one swallow."	2
6	90 ml of water, via 8-oz cup, uninterrupted	"Take this cup and drink the whole thing slow and study but without stopping."	1
7	5 ml of vanilla pudding, via spoon, single swallow	"Put all of this in your mouth and try to swallow it in just one swallow."	2
8	Self-selected volume of cracker, hand-delivered, single swallow	"Take one normal size bite, whatever is normal for you, chew it, and swallow it in just one swallow whenever you're ready."	2

defined by VASES. Once this frame was identified, raters recorded the presence of bolus on each of the six anatomic landmarks—more than one landmark could be selected, not just the "deepest" location. If no bolus was observed at the onset of "during the swallow," then the bolus was judged to be "within the oral cavity only" and was determined not to be within the pharynx. If the onset of "during the swallow" was not visualized (e.g., due to bolus flow obstructing the camera lens and due to velum abutting camera lens prior to onset), then bolus location at swallow onset was not rated, and data were missing for that trial.

Amount of Pharyngeal Residue, Penetration, and Aspiration

Visuoperceptual estimations of the amount of residue filling (oropharynx and hypopharynx) or covering (epiglottis, vestibule, vocal folds, and subglottis) each of the six anatomic structures were rated for each swallow trial using VASES percentage-based ratings. Ratings typically range from 0% to 100%, though > 100% is possible for the oropharynx, hypopharynx, vocal folds, and subglottis. For example, if the entire subglottic shelf was coated with residue and residue was also seen in the trachea, then ratings would exceed > 100%. Residue ratings of 0% indicated that residue was "absent," whereas residue ratings of > 0% indicated that residue was "present." Higher residue ratings indicated that a greater percentage of an anatomic structure was filled or covered with residue. Residue ratings were judged at the offset of the "after the swallow" temporal boundary. When possible, the amount of residue within the laryngeal vestibule, vocal folds, and subglottis was judged before coughs or throat clears.

PAS

The PAS is an 8-point ordinal scale used to estimate the depth of and response to penetration and aspiration (Rosenbek et al., 1996). A higher PAS score indicated greater depth of airway invasion and/or less efficient ejection. The PAS was rated using the anatomic and temporal boundaries defined by VASES, where PAS 2–3 indicated material was within the laryngeal vestibule but not on the vocal folds or in the subglottis, PAS 4–5 indicated material reached the level of the vocal folds but was not in the subglottis, and PAS 6–8 indicated material was within the subglottis below the lowest level of the vocal folds. Notably, residue on the epiglottis did not qualify as penetration (i.e., was PAS 1). Additionally, residue on the medial edge of the vocal folds or between the vocal folds but not necessarily on vocal fold tissue did not qualify as aspiration (i.e., was PAS 4 or 5) if it did not pass below the lowest level of the vocal folds/glottis. Four PAS scores were rated for each swallowing trial—one for each temporal boundary. Notably, if no airway invasion was observed "before the swallow" and no change in bolus flow was observed "after the swallow," then residue within the laryngeal vestibule, vocal folds, or subglottis was inferred to have occurred "during the swallow" within the period of endoscopic whiteout. The maximum (highest) PAS score across all four temporal boundaries was used as the primary PAS score for that swallowing trial.

Secondary Outcomes

Sip size/bite size of self-selected volumes. Cup weights were recorded immediately before and after each self-selected volume sip of water and bite of cracker. Weights were measured using a digital scale. Differences in weights were used to record the size of self-selected sips and bites.

Number of swallows. Number of swallows were counted "during the swallow" but not during any of the other three temporal boundaries. Number of swallows were estimated using two methods. First, the methods used to determine "during the swallow," as outlined by VASES, were used to identify when a swallow was initiated and present. Not previously described in the original publication of VASES, a sudden blurring of the endoscopic image (thought to be due to the sudden rise of the velum) associated with uninterrupted movement leading to the swallow was used as an indicator of the onset of "during the swallow" temporal phase. Second, perceived swallow sounds obtained from the FEES audio were used to aid in counting the number of swallows, especially when sustained endoscopic whiteout was observed and multiple swallows were suspected.

Data Analysis

FEES videos were segmented into individual video clips for each swallowing trial for analysis. The beginning of each video clip began when a new bolus was presented to the participant and announced by the endoscopist or assisting graduate intern. Each video clip ended immediately prior to the presentation of a new bolus trial and the audible announcement of that trial by the endoscopist or assisting clinician. Videos were stored digitally and analyzed in the order in which they were recorded.

Of the 584 video clips obtained, 341 of the FEES video clips were analyzed by pairs of independent raters. The independent raters were speech-language pathology graduate interns who completed 5 hr of VASES training (didactic lecture, group interpretation practice, and independent interpretation practice) led by the first author. Questions and answers related to VASES and independent rating practice were addressed throughout the VASES training prior to beginning the analysis for this study. The remaining 243 video clips were obtained after

the speech-language pathology graduate students completed their internship. Therefore, these 243 video clips were analyzed only by the first author. The first author also performed discrepancy ratings for the paired ratings, as described below. All raters were blinded to participant demographic information and to the paired ratings.

For each swallow, raters measured bolus location at swallow onset, the number of swallows completed "during the swallow," residue for each anatomic landmark, and PAS for each temporal boundary. Notably, residue ratings were made offline using a visual analogue scale (Curtis, Borders, Perry, et al., 2022), which simultaneously displayed a whole number integer numerical value (Curtis, Borders, & Troche, 2022)—both of which have been validated for VASES.

For paired ratings, residue ratings were considered to be in agreement if they differed by ≤ 10% and if both raters indicated residue was either present (> 0%) or absent (0%). Paired residue ratings that were in agreement were averaged together and used for data analysis. Residue ratings were considered to be in disagreement if the paired ratings differed by > 10%, or if one rater indicated residue was "present" but the other rater indicated that residue was "absent." Residue ratings that were in disagreement were rerated by the first author and used for data analysis. The first author was blinded to the original paired ratings, had 9 years of experience performing and interpreting FEES, and was involved in the original development of VASES. Bolus location at swallow onset and PAS ratings were considered to be in agreement if ratings matched exactly. Ratings that did not match exactly were considered to be in disagreement and were resolved by the first author.

Statistical Analysis

All data were statistically analyzed using R Version 4.1.1 (R Core Team, 2021). Data and R code were made openly available in the Open Science Framework repository (https://osf.io/4anzm/) for data transparency and reuse by clinicians and researchers.

The first author reanalyzed 10% of their original video clips to examine intrarater reliability. The first rater then reanalyzed 20% of the dual-rated video clips to examine interrater reliability. Intraclass correlation coefficients (ICCs) were used to examine the reliability of the six residue ratings since these data are continuous. ICCs were calculated using a two-way, random effects, absolute agreement, single rater model. Cohen's kappa (κ) was used to examine reliability for bolus location at swallow onset measure since this represents dichotomous (presence vs. absent) nominal data. Weighted kappa (κ_w) was used to measure reliability of the number of swallows and PAS since these measures are ordinal in nature. Linear weights were applied to kappa for the number of swallows outcome since the difference between two adjacent categories (one to two swallows) is the same for all adjacent categories (e.g., two to three swallows, three to four swallows, four to five swallows, etc.). Quadratic weights were applied to kappa for the PAS outcome since the difference between two adjacent categories is not conceptually linear in nature (Steele & Grace-Martin, 2017). Descriptive statistics were also used to characterize reliability, which included percentage of absolute agreement (number of swallows, bolus location at swallow onset, PAS) and average difference in reliability ratings (residue).

Descriptive statistics were used to characterize VASES norms. Descriptive statistics for bolus location at swallow onset, number of swallows, and PAS included frequency distributions. Descriptive statistics for the residue ratings included proportion of swallows where residue was absent (0%) and the mean, median, minimum, maximum, standard deviation, interquartile range (IQR), and percentiles of residue ratings when residue was present (> 0%).

Results

Thirty-nine adults met the inclusion criteria and completed the study (see Table 2). Of these 39 participants, eight (20%) were < 40 years old, 20 (51%) were 40–59 years old, 10 (25%) were 60–80 years old, and one (2.5%) was > 80 years old. Twenty participants were cis female and 19 were cis male. Thirty-eight participants completed all 15 trials. One participant completed 14 of the trials, with one of the two pudding trials missing. In total, this study yielded an analysis of 584 trials. A summary of the 584 trials, aggregated across swallow conditions, is outlined below. Normative data for each of the 15 swallowing trials are further outlined in Supplemental Material S1 for greater detail. Intra- and interrater reliability outcomes are outlined in Table 3.

Number of Swallows

Across all swallow conditions, with the exclusion of the 90-ml sequential swallowing condition, participants completed one swallow for 78% of trials (n = 425), two swallows for 19.1% of trials (n = 104), and three swallows for 2.9% of trials (n = 16). More swallows were observed for the "natural" self-selected volume sips of water compared to the "single-swallow" self-selected volume sips of water. Specifically, one, two, and three

Table 2. Demographic information.

Variable	Total (*N* = 39)
Age (years)	
M (*SD*)	50.2 (14.5)
Mdn [Q1, Q3]	48.0 [40.5, 60.0]
Min, max	27.0, 83.0
Height (in.)	
M (*SD*)	67.2 (2.86)
Mdn [Q1, Q3]	67.0 [65.0, 69.0]
Min, max	62.0, 72.0
Weight (lbs)	
M (*SD*)	161 (29.3)
Mdn [Q1, Q3]	160 [140, 179]
Min, max	110, 233
Body mass index	
M (*SD*)	25.1 (5.12)
Mdn [Q1, Q3]	24.4 [21.3, 27.2]
Min, max	18.5, 37.7
Sex	
Female	20 (51.3%)
Male	19 (48.7%)
Gender	
Man	19 (48.7%)
Woman	20 (51.3%)
Race/ethnicity	
Asian	1 (2.6%)
Black or African American	10 (25.6%)
Hispanic or Latino/a	5 (12.8%)
Multiracial	3 (7.7%)
White	20 (51.3%)

swallows accounted for 60%, 33%, and 6% of trials, respectively, for "natural" self-selected volume sips of water compared to 78%, 22%, and 0% of trials for the "single-swallow" self-selected volume sips of water.

Sip Size and Bite Size

Sip sizes for the self-selected volume cup sips of water were similar between the "natural" and "single-swallow" swallowing conditions (see Table 4). The median size of self-selected volume sips of water was 19.0 ml (IQR: 13.3–25.8) across all "natural" swallowing trials and was 17.5 ml (IQR: 12.3–22.0) across all "single-swallow" swallowing trials, regardless of the number of swallows completed during the swallows. These sip sizes were similar when only examining trials with one swallow during the trials. Specifically, the median size of self-selected volume sips of water was 18.0 ml (IQR: 13.0–26.0) for "natural" trials with only one swallow and was 16.0 ml (IQR: 12.0–22.0) for "single-swallow" trials with only one swallow.

The median bite size of the self-selected volume of cracker was 1.05 g (IQR: 0.81–1.58) across all cracker trials and was 1.02 g (IQR: 0.70–1.50) for cracker trials with only one swallow. The average starting weight of the saltine crackers was 3.10 g, demonstrating that the median bite size of the cracker during the FEES was 33% of the cracker's initial mass.

Bolus Location at Swallow Onset

Boluses were observed within endoscopic viewing plane (pharynx and/or larynx) at the onset of the "during the swallow" temporal phase for 41.8% of trials. For the remaining 58.2% of trials, no bolus was observed within the endoscopic viewing plane at the onset of the swallow, suggesting that swallows were initiated with boluses only in the oral cavity for these trials. When boluses were observed in the pharynx or larynx at the onset of the swallow, they were noted to be within the oropharynx for

Table 3. Rater reliability.

	Intrarater reliability			Interrater reliability		
Variable	Estimate	95% CI	Descriptive	Estimate	95% CI	Descriptive
Number of swallows	0.710	[0.410, 1.009]	90.0%	0.624	[0.455, 0.792]	83.6%
Oropharyngeal residue	0.931	[0.860, 0.966]	0.7%	0.938	[0.904, 0.961]	0.8%
Hypopharyngeal residue	0.698	[0.460, 0.843]	0.3%	0.696	[0.555, 0.798]	0.6%
Epiglottic residue	0.955	[0.909, 0.978]	0.8%	0.760	[0.639, 0.843]	1.9%
Laryngeal vestibule residue	0.968	[0.933, 0.984]	0.4%	0.960	[0.936, 0.975]	0.8%
Vocal fold residue	0.979%	[0.957, 0.990]	0.1%	0.946	[0.915, 0.966]	0.05%
Subglottic residue	N/A	N/A	N/A	1.0	[1.00, 1.00]	0.0%
PAS	1.0	[0.636, 1.36]	100.0%	0.839	[0.610, 1.00]	93.2%
Bolus location at swallow onset	0.738	[0.481, 0.994]	96.7%	0.44	[0.210, 0.669]	76.7%

Note. Reliability estimates are Cohen's kappa for "number of swallows," weighted (linear) kappa for "bolus location at swallow onset," weighted (quadratic) kappa for "PAS," and intraclass correlation coefficient for all residue outcomes. Descriptive statistics include percentage of absolute agreement (%) for "number of swallows," "bolus location at swallow onset," and "PAS" and the average difference in ratings for all residue outcomes. CI = confidence interval; N/A = not available; PAS = Penetration–Aspiration Scale.

Table 4. Natural sip and bite sizes.

Sip size/bite size	Natural	Single swallow	
	Thin (ml) (*n* = 78)	Thin (ml) (*n* = 78)	Regular (g) (*n* = 78)
Mean (*SD*)	20.7 (10.7)	19.0 (10.1)	1.33 (0.722)
Mdn [Q1, Q3]	19.0 [13.3, 25.8]	17.5 [12.3, 22.0]	1.05 [0.809, 1.58]
Percentiles:			
1%, 2.5%, 5%, 10%	5.7, 6.9, 8.7, 10.0	4.7, 5.0, 5.8, 8.7	0.47, 0.54, 0.57, 0.63
90%, 95%, 97.5%, 99%	34.0, 37.8, 43.6, 55.1	33.0, 42.0, 43.3, 47.7	2.54, 3.02, 3.03, 3.05
Min, max	5.00, 69.0	4.00, 50.0	0.440, 3.09

39.2% of trials, within the hypopharynx for 14.4% of trials, on the epiglottis for 12.0% of trials, in the laryngeal vestibule for 1.0% of trials, and/or on the vocal folds for 0.2% of trials. Swallows were never initiated with bolus in the subglottis at the onset of the swallow.

Residue Ratings

Oropharyngeal Residue

Oropharyngeal residue ratings across the 584 trials are displayed in Figure 1. Oropharyngeal residue was present (> 0%) for 94.2% of trials. When oropharyngeal residue was present, the median amount of residue was estimated to be 2.0% (IQR: 1.5–3.0), with similar residue ratings across bolus consistencies and volumes. Oropharyngeal residue was absent (0%) for 5.8% of trials. Residue was absent most frequently for crackers (28.2% of trials), followed by pudding (7.8% of trials) and water (1.4% of trials).

Hypopharyngeal Residue

Hypopharyngeal residue ratings are displayed in Figure 2. Hypopharyngeal residue was present for 86.6% of swallowing trials. When hypopharyngeal residue was present, the median amount of residue was estimated to be 1.5% (IQR: 1.0–2.0), with similar residue ratings across consistencies and volumes. Hypopharyngeal residue was

Figure 1. Oropharyngeal residue ratings (*N* = 584). Orange values represent the number of ratings where residue was absent (0%). Blue values represent the number of ratings where residue was present (> 0%).

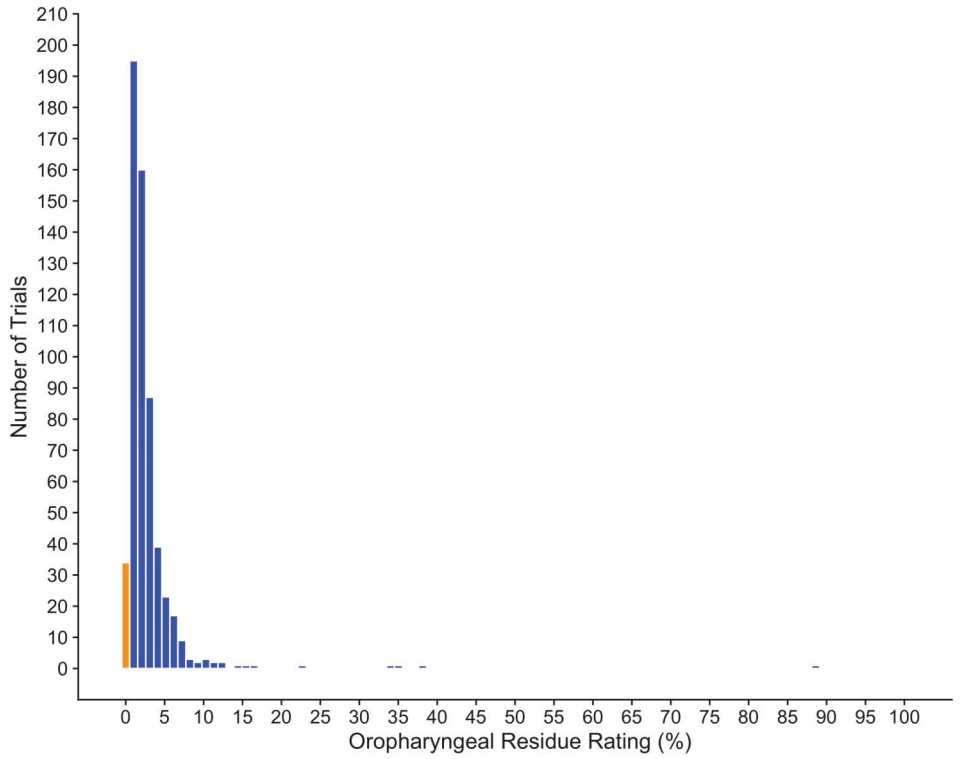
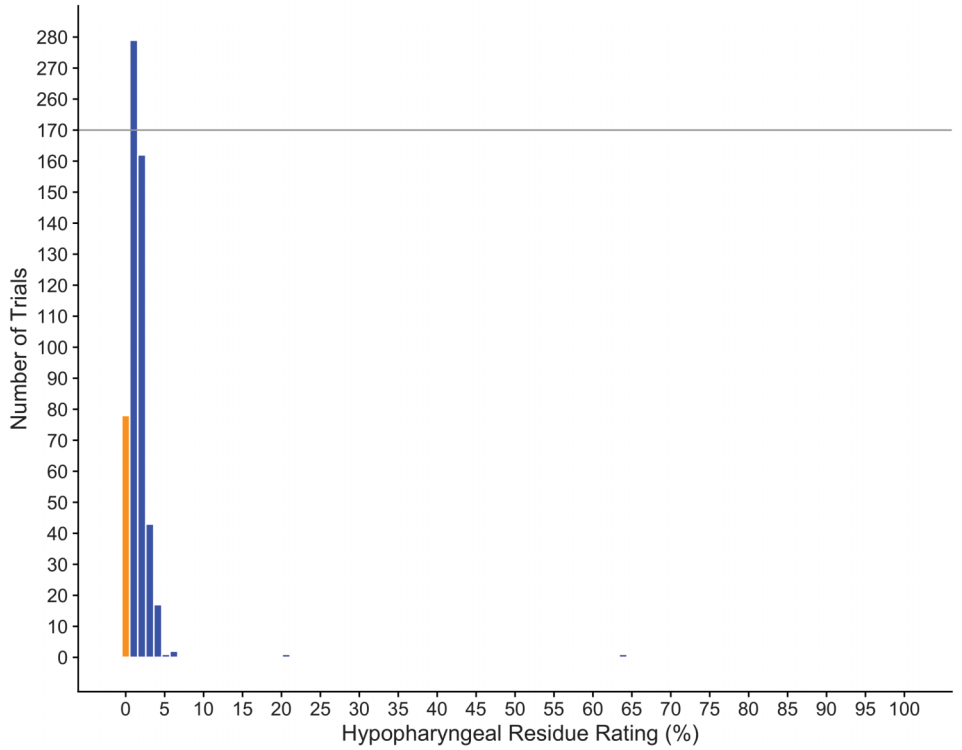


Figure 2. Hypopharyngeal residue ratings (N = 584). Orange values represent the number of ratings where residue was absent (0%). Blue values represent the number of ratings where residue was present (> 0%). The gray line represents an axis break, used to enhance visualization for the highly skewed data.



absent for 13.4% of swallowing trials. Residue was absent most for crackers (57.7% of trials), followed by pudding (23.4% of trials) and water (3.5% of trials).

Epiglottic Residue

Epiglottic residue ratings are displayed in Figure 3. Epiglottic residue was present for 65.1% of swallowing trials. When epiglottic residue was present, the median amount of residue was estimated to be 3.0% (IQR: 2.0–6.0), with similar residue ratings across consistencies and volumes. Epiglottic residue was absent for 34.9% of swallowing trials. Residue was absent most frequently for crackers (82.1% of trials), followed by pudding (57.1% of trials) and water (22.4% of trials).

Laryngeal Vestibule Residue

Laryngeal vestibule residue ratings are displayed in Figure 4. Laryngeal vestibule residue was present for 31.9% of water trials but 0% of pudding and cracker trials. When laryngeal vestibule residue was present for water, the median amount of residue was estimated to be 3.0% (IQR: 2.0–4.5), with a similar amount across bolus volumes. Laryngeal vestibule residue was absent for 68.1% of water trials and 100% of pudding and cracker trials.

Vocal Fold Residue

Vocal fold residue ratings are displayed in Figure 5. Vocal fold residue was present for 6.8% of water trials but 0% of pudding and cracker trials. When vocal fold residue was present for the water trials, the median amount of residue was estimated to be 3.5% (IQR: 2.5–7.0), with a similar amount of vocal fold residue across bolus volumes. Vocal fold residue was absent for 93.2% of water trials and 100% of pudding and cracker trials.

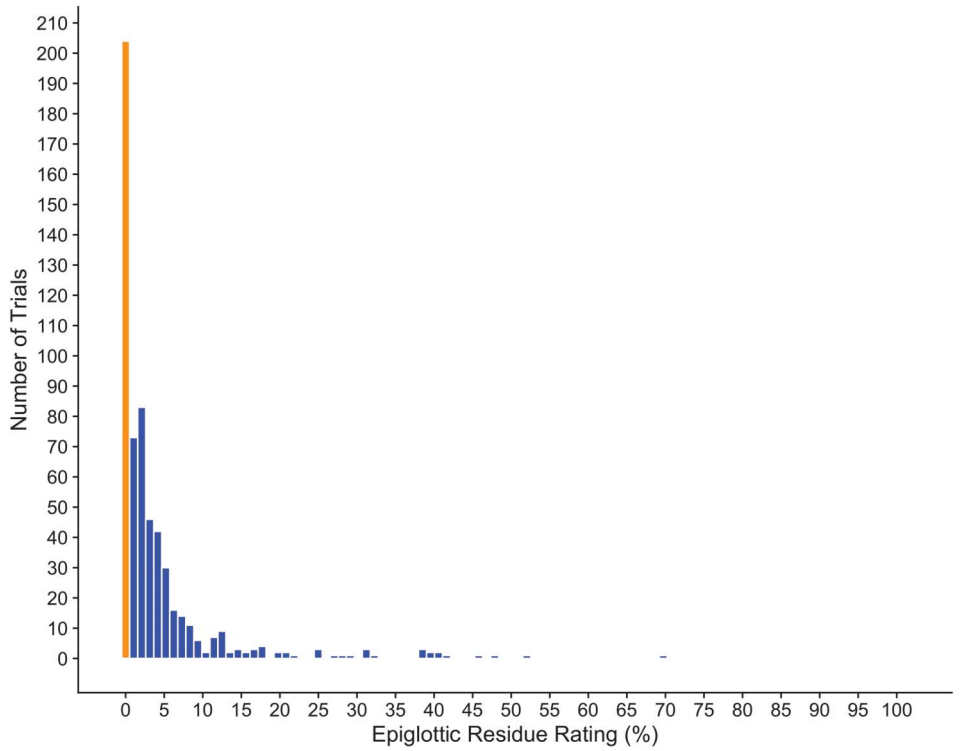
Subglottic Residue

Subglottic residue ratings are displayed in Figure 6. Subglottic residue was present for five water trials but was not present for any of the pudding or cracker trials. The five subglottic residue ratings were 1% (self-selected volume of green opaque water; PAS 8), 3% (20 ml of white coating water; PAS 8), 10% (self-selected volume of white coating water; PAS 7), 24% (90 ml of white coating water; PAS 7), and 90% (10 ml of white coating water; PAS 7).

PAS

PAS scores are displayed in Figure 7. PAS 1 was the most common score, accounting for 75.3% of trials,

Figure 3. Epiglottic residue ratings (N = 584). Orange values represent the number of ratings where residue was absent (0%). Blue values represent the number of ratings where residue was present (> 0%).



followed by PAS 3 (18.8% of trials), PAS 5 (4.3% of trials), PAS 2 (0.7% of trials), PAS 7 (0.5% of trials), PAS 8 (0.3% of trials), and PAS 4 and 6 (0% of trials). Thirty-five participants demonstrated penetration (PAS 2–5) on at least one trial, four of whom also demonstrated aspiration (PAS 6–8). Four of the 39 participants never demonstrated penetration or aspiration.

Five events of penetration and aspiration were noted to occur outside the "during the swallow" phase. Specifically, PAS 3 occurred once "between bolus trials"—this was the maximum PAS for that trial. PAS 4 occurred once "after the swallow"—however, this was not the maximum PAS for that trial since a PAS 5 was also observed for that trial. PAS 5 occurred once "before the swallow" and once "after the swallow"—these were the maximum PAS scores for both trials. Lastly, PAS 6 occurred once "after the swallow"—however, this was not the maximum PAS for that trial since a PAS 7 was observed during the swallow.

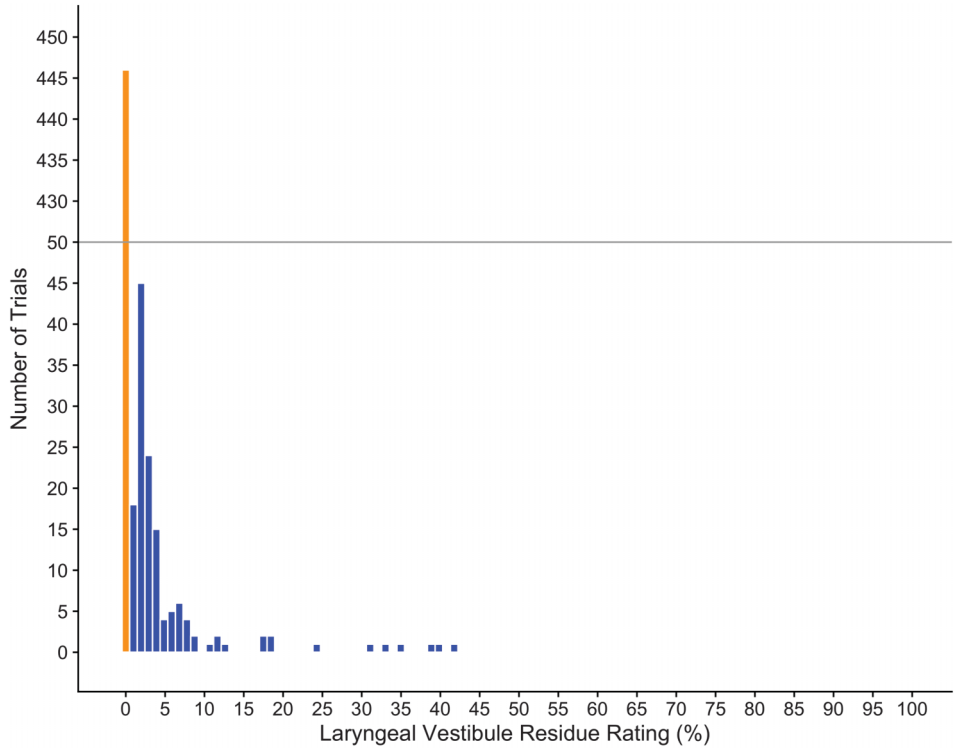
Discussion

This study is a first step toward the development of a large normative data set for FEES using VASES. While this study is limited in part by a small sample size (N = 39) and restricted age range (n = 30 less than 60 years), it provides preliminary reference values that clinicians can use when interpreting FEES and also provides a starting point to make comparisons to previously completed dysphagia research.

Bolus Location at Swallow Onset

Dua et al. (1997) previously investigated normative findings related to the frequency of boluses being present in the pharynx prior to swallow initiation during FEES. During that study, healthy adults underwent a FEES while consuming a 1,000-cal meal composed of a variety of foods and liquids. The researchers found that 76% of food trials and 60% of drinking trials were initiated with boluses in the pharynx or on the epiglottis. In our study, the most similar swallowing conditions were the self-selected volumes of water (natural condition) and crackers (single-swallow condition). During these swallowing conditions, we observed 59% of cracker swallows and 41% of water swallows were initiated with boluses in the pharynx or on the epiglottis. One reason for differences in findings may be related to types of boluses used and swallowing conditions. Dua et al. allowed participants to eat and drink foods and liquids continuously as they would during a typical meal. This study, however, was more controlled

Figure 4. Laryngeal vestibule residue ratings (N = 584). Orange values represent the number of ratings where residue was absent (0%). Blue values represent the number of ratings where residue was present (> 0%). The gray line represents an axis break, used to enhance visualization for the highly skewed data.



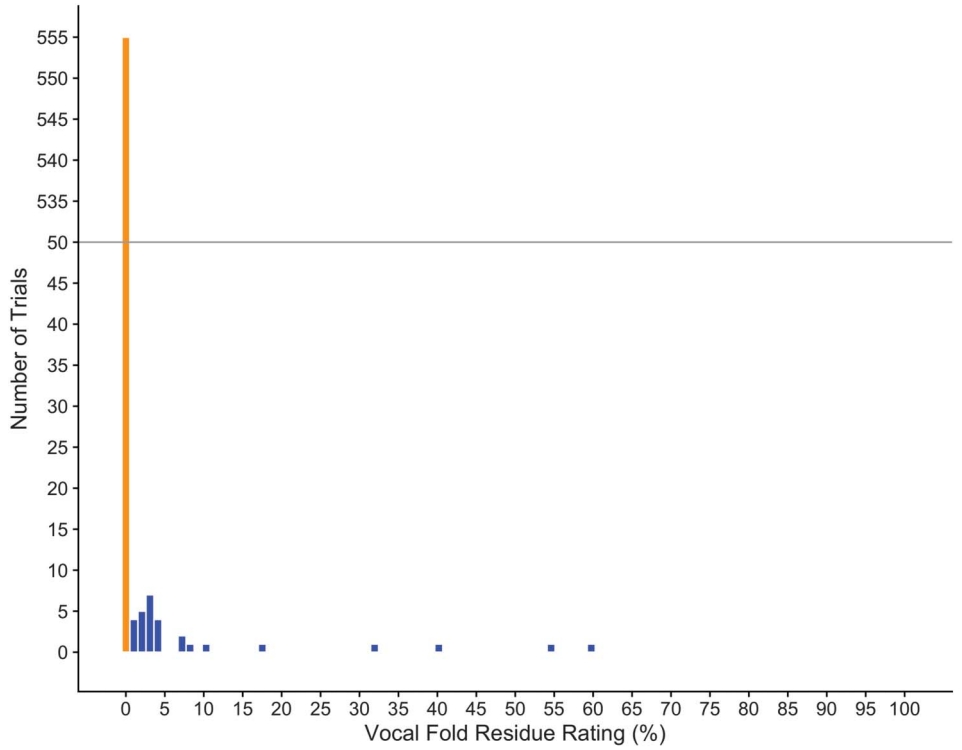
with pauses after every trial and pauses between each swallowing condition. Second, the types of foods and drinks tested were different between the two studies. While the present VASES study included water, pudding, and saltine crackers, the Dua study included cheeseburgers, sodas, milkshakes, and fries.

Despite differences in the frequency of bolus location at swallow onset between these two studies, both studies demonstrated that observations of boluses within the pharynx and/or on the epiglottis prior to swallow initiation is a normal finding during FEES in nondysphagic, community-dwelling, healthy adults. This finding is consistent with the "process model of feeding" proposed by Matuso and Palmer, who demonstrated that aggregation of boluses in the oropharynx prior to swallow initiation is deliberate, occurring even against gravity (Matsuo & Palmer, 2009). These results are also consistent with previous findings reported in healthy adults during videofluoroscopic swallow studies (Humbert et al., 2018; Steele et al., 2019).

Pharyngeal Residue

Small amounts of pharyngeal residue have been frequently observed in research examining healthy adult swallows during FEES (Butler, Stuart, Markley, & Rees, 2009; de Lima Alvarenga, Abrahão, et al., 2018; de Lima Alvarenga, Dall'Oglio, et al., 2018; Kamarunas et al., 2014; Muhle et al., 2020; Veiga et al., 2014). The findings from this study support these previous research findings. First, the presence pharyngeal residue was observed in the oropharynx for 72%–99% of trials and in the hypopharynx for 42%–97% of trials. Second, when pharyngeal residue was present, it was observed to be relatively small, with ratings typically between 2% and 3% across bolus consistencies. Interestingly, pharyngeal residue ratings of 2%–3% are similar to percentage-based residue ratings that have been previously reported in healthy adults during videofluoroscopic swallow studies using both bolus clearance estimation methods (Leonard et al., 2022) and anatomically defined normalized residue ratio scale methods (Steele et al., 2019). However, it should be noted that sips of clear water were intermittently used between trials. This was done to clear pharyngeal and laryngeal residue from previous swallows so that each individual swallow condition could be judged independently. Therefore, it is possible that residue within the pharynx and larynx may have accumulated throughout the protocol if uncleared. Clinicians should consider this when interpreting FEES

Figure 5. Vocal fold residue ratings (N = 584). Orange values represent the number of ratings where residue was absent (0%). Blue values represent the number of ratings where residue was present (> 0%). The gray line represents an axis break, used to enhance visualization of the highly skewed data.



findings and referring to the present preliminary reference values.

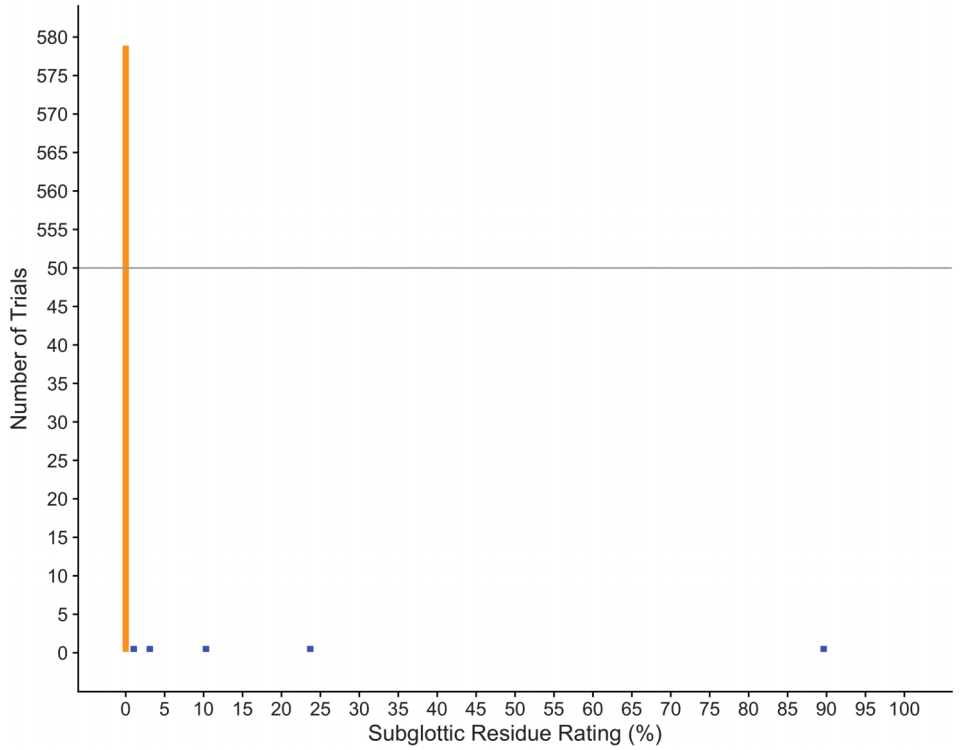
Penetration–Aspiration

There is a relatively large body of literature examining the presence of penetration and/or aspiration in healthy adults during FEES (Aviv et al., 1998; Badenduck et al., 2014; Butler et al., 2010, 2011, 2018; Butler, Stuart, & Kemp, 2009; Butler, Stuart, Markley, & Rees, 2009; de Lima Alvarenga, Abrahão, et al., 2018; de Lima Alvarenga, Dall'Oglio, et al., 2018; Dua et al., 1997; Kamarunas et al., 2014; Muhle et al., 2020; Veiga et al., 2014). The most comprehensive of these studies was published by Butler et al. in 2018 (Butler et al., 2018). In that study, 203 healthy adults across the age continuum underwent FEES while swallowing 32 liquid boluses, which varied by bolus size (5–20 ml), liquid type (milk vs. water), and bolus delivery method (cup vs. straw). Penetration (PAS 3–5) was observed in 50% of the participants, accounting for 9.4% of swallows, whereas aspiration (PAS 6–8) was observed in 18% of the participants, accounting for 1.6% of swallows, 64% of which were silent aspiration events.

When assessing the swallowing conditions in our study that were most similar to the swallow conditions in Butler et al.'s (2018) study (i.e., water trials < 90 ml), penetration accounted for 29.7% of trials, and aspiration accounted for 0.8% of swallows, 40% of which were silent. While silent and nonsilent aspiration rates appear similar to those reported by Butler et al., our study observed penetration approximately to occur 3 times more often. This is surprising given that VASES excludes material on the epiglottis as a marker for penetration, whereas the Butler et al. study included epiglottis residue as a marker for penetration—a method of interpretation that should lead to a lower, not higher, frequency of penetration for our study. One potential explanation for the greater prevalence of penetration observed in this study was our use of white dye for all water trials. This was not done in the Butler et al. study and has been found to increase detection rates of penetration during FEES (Curtis et al., 2019, 2020).

The amount of penetration and aspiration, not just the presence of it, is likely an important marker of swallow function and long-term health outcomes. Despite that, few studies have characterized "normal" amounts of penetration and aspiration. Though not formally measured or analyzed in Butler et al.'s (2018) study, the authors indicated that the majority of aspiration events ranged from "pea-sized amount" to a "small thin line."

Figure 6. Subglottic residue ratings (N = 584). Orange values represent the number of ratings where residue was absent (0%). Blue values represent the number of ratings where residue was present (> 0%). The gray line represents an axis break, used to enhance visualization of the highly skewed data.



Research by Steele et al. sought to characterize the amount of aspiration and penetration in healthy adults during videofluoroscopy using dichotomous ratings of "trace" and "more than trace" (Steele et al., 2019). While no events of aspiration were observed in the Steele et al. study, their research found that penetration was estimated to be "trace" for approximately 78% of the penetration events and "more than trace" for approximately 22% of the penetration events. The findings from this study appear to support these results. Specifically, we found that when penetration was present, it typically led to residue ratings of approximately 3% for the laryngeal vestibule and vocal folds (though residue ratings up to 60% were observed). Similarly, we found that when aspiration was present, the median amount of aspiration when present was 10%, with a total range of 1%–90%.

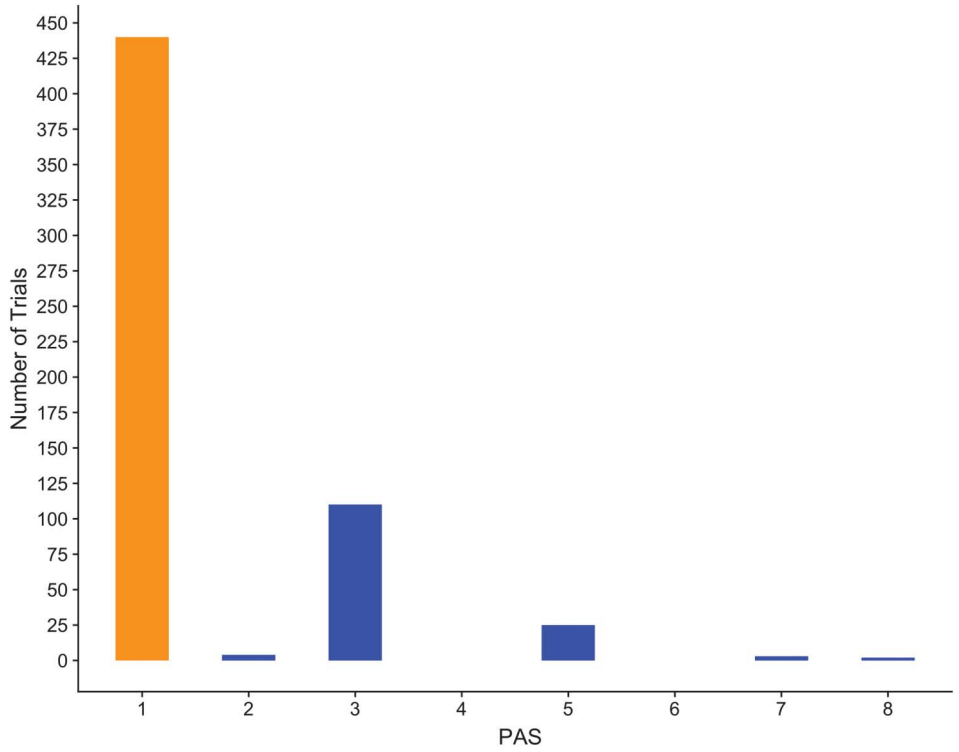
It is interesting to note that recent research from our group has found that aspiration amount is a significant predictor for explaining the absence versus presence of a cough or throat clear (silent vs. nonsilent aspiration) in people with neurological disease (Curtis, Borders, Dakin, & Troche, 2022). Specifically, silent aspiration had a median subglottic residue rating of 9%, whereas nonsilent aspiration had a median subglottic residue rating of 22%. In this study with healthy adults, only five instances of aspiration were observed, which precluded the ability to examine this same phenomenon in detail. However, the two events of silent aspiration events (PAS 8) had subglottic residue ratings of 1% and 3%, whereas the nonsilent aspiration events (PAS 7) had subglottic residue ratings of 10%, 24%, and 90%. This suggests that nondysphagic, healthy adults may exhibit similar relationships between aspiration amount and the presence of silent versus nonsilent aspiration as has been seen in people with neurological disease, though larger sample sizes are needed.

Number of Swallows, Sip Size, and Bite Size

Sip size, bite size, and number of swallows are important for providing the context of findings related to pharyngeal residue, penetration, and aspiration during FEES. For example, less residue is expected with small bites and sips and with a greater number of swallows. Therefore, it is important to accompany bolus-related outcome measures, as is done in this study, with information about sip size, bite size, and number of swallows.

Recent research identified that healthy adults complete sips of barium within a single swallow for

Figure 7. Maximum Penetration–Aspiration Scale (PAS) ratings (N = 584) across the four temporal boundaries defined by the Visual Analysis of Swallowing Efficiency and Safety. Orange values represent the number of trials where airway invasion (penetration/aspiration) was absent (PAS 1). Blue values represent the number of trials where airway invasion was present (PAS > 1).



approximately 80% of trials during videofluoroscopic swallow studies, with more than one swallow accounting for approximately 20% of trials (Steele et al., 2019). In our study, the number of swallows was estimated using endoscopic findings and swallow sounds. Despite this limitation, results from our study are relatively consistent with those from videofluoroscopy. Specifically, 61%–78% of the self-selected volume cup sips of water in this study were completed within a single swallow, whereas 22%–39% of the trials were completed in more than one swallow—depending on the swallowing instruction provided. During the "natural" swallowing condition, participants used "more than one swallow" for 39% of trials, whereas during the "single-swallow" swallowing condition, participants used "more than one swallow" for only 22% of trials. Therefore, it would appear as though instructing examinees to use a single swallow may reduce the frequency of piecemeal deglutition during FEES. This is important since the "single-swallow" instruction may be useful to reduce the frequency of piecemeal deglutition and ensure that the volume of the sip and bite taken is the same volume that is being swallowed.

In this study, the average sip size for the self-selected volume cup sips of water was approximately 20 ml. Average sip size did not appear to differ between the "natural" (20.7 ml) and "single-swallow" (19.0 ml) swallowing conditions despite potential differences in number of swallows per trial. While these sip sizes appear larger than the 12-ml sips that have been reported during videofluoroscopy (Steele et al., 2019), they appear relatively consistent with the 20- to 23-ml sip sizes observed during normal, nonheld, noncued, cup sips of water (Adnerhill et al., 1989; Bennett et al., 2009; Kim et al., 2013; Lawless et al., 2003; Nilsson et al., 1996). One reason the sip sizes in this study may be larger than those observed during videofluoroscopy may be related to the fact that water with food dye, as opposed to barium, is being consumed (Bennett et al., 2009). In terms of bite size, the average bite was approximately 33% of the original size of the saltine cracker. This is consistent with previous normative data from the Test of Mastication and Swallowing Solids, which has found that most healthy adults consume a saltine cracker in two to three bites (Huckabee et al., n.d.).

Limitations and Future Directions

Due to the preliminary nature of this study, a convenience sample of 39 adults was obtained, which limited the ability to recruit a diverse group of adults across the continuum of age, sex, gender, race, and ethnicity. This is

important given that measures of swallowing physiology and function may change based on these demographic variables.

While the age of the participants in this study ranged from 27 to 83 years, most participants were between 40 and 60 years of age. Age has been consistently found to relate to spatial and temporal swallowing kinematics (Bhutada et al., 2020; Leonard et al., 2000) and respiratory–swallow coordination (Martin-Harris et al., 2005), but its influence on functional swallowing outcomes is less conclusive (Bhutada et al., 2020; Butler et al., 2018; Garand et al., 2019; Robbins et al., 1992). Given these discrepancies, future research should include more adults across the age continuum to better examine the influence of age on functional swallowing outcomes.

The sample in this study had a relatively even distribution of cisgender males (n = 19) and cisgender females (n = 20); however, nobody in this study identified as transgender, gender nonbinary/nonconforming, or intersex. This is important given that sex and gender can be a significant predictor of functional swallowing outcomes. For example, cisgender males typically exhibit airway invasion more frequently than cisgender females (Garand et al., 2019) and initiate swallows with boluses closer to the oral cavity than cis females (Bhutada et al., 2020). However, gender is not a binary variable. Furthermore, a person's gender may not align with the sex assigned at birth (e.g., trans female or trans male). To the author's knowledge, no research has examined the influence of sex and gender on functional swallowing outcomes or swallowing physiology beyond the cisgender male and cisgender female binary domains. Therefore, given the important contribution of sex and gender on functional swallowing outcomes, future normative research should continue to recruit a heterogenous and representative sampling of people across the continuum of sex and gender to enhance diagnostic outcomes of all potential patient populations.

This study also included participants who identified as Asian (n = 1), Black or African American (n = 10), Hispanic or Latino/a (n = 5), multiracial (n = 3), or White (n = 20). This is important given that emerging data suggest that race and ethnicity may contribute to small differences in some (Bhutada et al., 2020), but not all (Martin-Harris et al., 2003, 2005), aspects of swallowing physiology. Therefore, efforts should be made in future research to recruit a diverse sampling of people of various races and ethnicities to further explore the impact of race and ethnicity on swallowing physiology and function.

Lastly, it is important to consider that normative findings observed during FEES and VASES likely vary based on swallowing conditions and FEES-specific logistical considerations (Curtis, 2022). Whereas bolus size, bolus consistency, and contrast agents have all been found to influence functional swallowing outcomes, the effect of endoscopic technology is less well understood. Specifically, it is unclear how endoscopic equipment factors such as camera type (fiberoptic vs. distal chip), light source (xenon, LED, stroboscopy, and narrowband imaging), brightness, resolution capabilities, and magnification influence interpretation of functional swallowing outcomes. Therefore, future research should examine the effects of these endoscopic equipment and procedural factors to better determine how normative data generalize across conditions.

Conclusions

This study sought to characterize normal swallowing during FEES using VASES and to establish preliminary reference values for VASES that many clinicians and researchers assist in the diagnosis of oropharyngeal swallowing dysfunction. A summarized description of the preliminary findings for the entire 15-trial protocol was outlined in the above results and discussion sections. However, functional swallowing outcomes can vary as an effect of bolus size, bolus consistency, and the contrast agent used during FEES (Curtis, 2022). Therefore, clinicians and researchers are encouraged to refer to the supplemental document of this study to make diagnostic comparisons with the swallow condition(s) that most closely matches the swallowing condition(s) of diagnostic interest (see Supplemental Material S1).

While this study is an important first step in establishing norms for FEES and VASES, people using this study to interpret FEES should be mindful that the reference values from this study are from a relatively small study sample (N = 39), with most people (n = 30) being 27–60 years old and only nine people being 61–83 years old. Future research should expand on the current norms by including a greater number of people across the age continuum and with greater racial, ethnic, and gender diversity.

Author Contributions

James A. Curtis: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – reviewing & editing. **James C. Borders:** Formal analysis, Project administration, Software, Validation, Visualization, Writing – reviewing & editing. **Avery E. Dakin:** Formal

analysis, Project administration, Software, Validation, Visualization, Writing – reviewing & editing. **Michelle S. Troche:** Funding acquisition, Methodology, Resources, Supervision, Writing – reviewing & editing.

Data Availability Statement

All data and R code from this study are openly available in the Open Science Framework repository at https://osf.io/4anzm/.

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