LIQUID BOLUS VOLUME IN HEALTHY PERSONS ACROSS THE LIFESPAN

by

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ACROSS THE LIFESPAN

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ABSTRACT

The purpose of this study was to determine the liquid bolus volume during swallowing in older healthy adults compared with younger healthy adults. Further, we sought to identify if the method of bolus delivery and texture, common adaptations applied in clinical practice, impacted the bolus volume consumed in healthy persons. Participants were recruited from Texas Christian University faculty, staff, and students using voluntary response, convenience, and snowball sampling due to the COVID-19 pandemic. Younger healthy ($n = 12$, aged 20-38 years) and older healthy participants ($n = 10$, aged 53-70 years) completed six experimental swallow trials of a thin liquid water bolus during four counterbalanced conditions: non-cued by cup, cued by cup, straw delivery, and carbonated by cup. An independent samples t-test demonstrated that older healthy persons' bolus volume in non-cued water swallows (M=12.41 mL, SD=8.01) was not statistically different from the younger healthy persons' (M=15.04, SD=8.62), $t(86)=1.47$, $p=.146$. Paired sample t-tests to examine differences between conditions in healthy persons were also not significant: cued single sip by cup compared to non-cued single sip by cup ($p= .498$), single straw sip compared to non-cued single sip by cup ($p= .268$), carbonated single sip and non-cued single sip (non-carbonated) by cup ($p=.948$). The findings in this pilot study suggest that the liquid bolus volume typically consumed in single sips was not impacted by age. Further, delivery method (straw or providing verbal cues) and texture (carbonated) did not alter the bolus size compared with a natural single liquid bolus by cup. However, a future study should include a larger sample of participants over the age of 65 to examine the effects of aging on liquid bolus volume.

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TABLE OF CONTENTS

BACKGROUND

Swallowing is a complex sequence of synergistic movements designed to transport a bolus, comprised of food or liquid, effectively and safely from the oral cavity to the stomach. To execute this sequence, a motor plan accounting for the temperature, texture, and size of the bolus is developed (Lawless et al., 2003). Sensory input is critical to all three phases of the swallow: the oral, pharyngeal, and esophageal phases, and is what triggers the onset of the pharyngeal swallow, or movement of the bolus through the pharynx (Steele et al., 2010). Sensory inputs are sent from the peripheral mechanoreceptors in the oropharyngeal tissue to the cortex and swallowing control center in the brainstem (Dodds et al., 1988) to enable real-time adjustments to the swallow motor plan for execution of a safe and effective swallow (McCoy & Desai, 2018). The duration and amplitude (i.e. degree) of muscle contraction and activity during the swallow can be attributed to changes in the bolus' consistency (Jean, 2001) and bolus size (Dodds et al.,1988). The magnitude of hyolaryngeal movement, a requisite component for adequate airway closure during the swallow, is impacted by the bolus' volume; thus, this suggests that afferent (sensory) input is sent from the oral cavity to central controls to modulate the motor plan to maintain a safe and effective swallow regardless of bolus size or texture.

In the oral phase of the swallow, a liquid bolus is held anteriorly against the hard palate and the upper teeth. There is a sealing of the oral cavity that occurs to prevent oropharyngeal spillage anteriorly by the lips and posteriorly by the velum and back of the tongue. The propulsion of the liquid bolus from the anterior to posterior oral cavity occurs when the tongue tip rises and the back of the tongue lowers (Matsuo & Palmer, 2008). Sensory inputs at the mechanoreceptors in the oral cavity at or near the anterior faucial pillars aid in triggering the pharyngeal motor pattern onset to propel the bolus through the pharynx and into the opening of the esophagus (Ertekin & Aydogdu, 2003). A robust sensorimotor swallow is imperative to aid in efficient oral intake to maintain a person's nutrition and hydration needs as well as maintaining airway safety. Alterations in sensory input or motor output for swallowing result in dysphagia, an impairment that can lead to dehydration, malnutrition, penetration/aspiration (food or liquid entrance in the airway), aspiration pneumonia, and/or increased risk of mortality (Kaneoka et al., 2018).

The influence of sensory inputs on the neuromodulation of swallow timing and synergistic motor activation is less understood than the central control mechanisms for coordinated motor movements. Additional investigation in this area may provide vital evidence to guide maximal motor function in swallowing. Earlier investigations in liquid bolus volume found the average single sip (liquid bolus volume) to range from 23.7 to 27.2 mL in healthy individuals (n=100; 49 males) (Lawless et al.,2003). Adnerhill et al. (1989) examined 60 healthy persons spanning 30-79 years of age for differences in bolus volume between water, barium contrast, and carbonated soda; the average single sip liquid bolus volume was 21 mL. Importantly, barium bolus, typically used in videofluoroscopic evaluations of swallowing, volumes were significantly smaller than the water and carbonated soda boluses. This may suggest that persons undergoing evaluation are not consuming barium liquid bolus volume trials that are commensurate with their natural oral intake habits in the home environment.

A small body of evidence suggests that bolus delivery methods, such as drinking from a straw, or bolus texture alter swallowing (Bennett et al., 2009). Single liquid boluses consumed when using a straw in 292 healthy persons averaged 25.6 mL in size (Nilsson et al., 1996). However, Clark et. al. (2014) noted that patients with poor bolus control may benefit from the control that a straw provides, especially in situations where the patient is cognitively or physiologically impaired. Carbonation has been found to increase swallow onset timing through the flood of sensory information gathered by the trigeminal nerve (Miura et al., 2009) although the impact of carbonation on bolus volume has not been studied. Additionally, delivering a verbal prompt to complete a swallow, such as “swallow now,” has been shown to alter swallow timing and coordination of the swallow (Daniels et al., 2007). Bennett et al. (2009) found that a smaller bolus volume (6 mL) is consumed when instructed to drink than when they were observed unknowingly during a drinking task (24 mL). This may support a long-standing hypothesis that verbal cues decrease bolus volume when compared to natural, non-cued drinking.

During the aging process, persons undergo a decrease in oral and pharyngeal sensations of taste, temperature, and tactile awareness (McCoy & Desai, 2018). The impact of these sensory changes on liquid bolus volumes for older healthy individuals is not yet known. Adnerhill et al. (1989) found no differences in single sip liquid bolus volumes in older healthy compared with younger healthy although additional studies are needed.

RESEARCH QUESTIONS

The purpose of this study was to determine the bolus volume in older healthy versus younger healthy persons in single sips of thin liquid by cup. We also aimed to compare natural swallows by cup with other bolus delivery and texture conditions which included cued single sip by cup, natural (non-cued) single sip by straw, and natural (non-cued) single sip with carbonated water by cup. We hypothesized that:

1. Older healthy persons will consume similar or larger bolus volumes than younger healthy.
2. Cued bolus volumes will be smaller than non-cued boluses.
3. Straw bolus volumes will be smaller than non-cued bolus volumes.
4. Carbonated bolus volumes will be smaller than non-cued bolus volumes.

PARTICIPANTS

We recruited participants from two pre-determined age groups: 18-39 years of age and 50+ years of age. Due to the COVID-19 pandemic, we were limited to recruitment from the Texas Christian University community (i.e. faculty, staff, or students). Recruitment was conducted using voluntary response, convenience, and snowball recruitment techniques with flyers, email, and word of mouth within the TCU community. All participants recruited were required to be in good health with no neurological disorders, neuromotor impairments, dry mouth (xerostomia), recent intubation (known to impact the swallow), or history of head/neck radiation.

METHODS

The study included: (1) a telephone screening and (2) a visit to the Laboratory of Applied Swallowing Research (LASR) in the Miller Speech and Hearing Clinic at TCU. For the study visit at TCU, all participants were required to adhere to COVID-19 protocol procedures which included temperature checks prior to building entry, completion of a health symptom screening, and handwashing. Each participant was required to wear their mask at all times except during the experimental procedures necessitating access to the oral structures.

Pre-experimental telephone screening

To determine eligibility to participate in the study, participants were required to complete a telephone screening outlining their medical history. Additionally, they were given a swallowing screen, the Eating Assessment Tool-10 (EAT-10)- a ten-question self-rating measure that determines the potential presence of abnormal swallowing (Belafsky et al., 2008). Participants scoring less than a three, the cut-off for normal swallowing, and a pass on the medical history review were invited to the laboratory to complete the in-person inclusion screening tasks and the experimental trials.

Instrument calibration procedures

Prior to the participant's arrival for their in-person visit, the instrumentation was calibrated. The spirometer (KoKo; Longmont, CO) was calibrated using a three-liter canister and adhering to the manufacturer guidelines and instrument screen prompts.

This task entailed withdrawing a plunger and pushing the plunger to insert a known volume (three liters) of air into the spirometer transducer.

Inclusion screening during in-person study visit

After completing the consenting process, participants completed a battery of assessments to ensure that they met the healthy parameters for the study. A Reflux Symptom Index (RSI) was administered to ensure that participants did not have symptoms of acid reflux which can negatively affect the swallow (Belafsky et al., 2002). Participants scored < 13 in order to participate. Participants also completed the Mini Mental State Examination (MMSE), scoring >21, to ensure adequate cognitive awareness to perform the study tasks (Folstein et al.,1975). An oral mechanism screening assessed the participants' facial structure and function with participation dependent on unremarkable findings. To screen respiratory function, participants completed a respiratory screening measure to determine their ratio for forced expiratory volume in one second to their forced vital capacity (FEV1/FVC), or total air that they can breathe out after a deep breath. This task was completed by the participant placing a new, single-use spirometer filter, attached to the spirometer transducer, between their lips with a secure seal; then, a nose clip was adhered to prevent nasal airflow for the screening task. The participant was provided verbal instruction for the task to assist in accurately timing the breath in (inspiration) followed by the forceful breath out (expiration). A ratio of 0.7 L/s or higher was requisite for participation in the study. Based on the GOLD (Global Initiative for Chronic Obstructive Lung Disease), a score of ≤ 0.70 suggests abnormal respiratory function (GOLD, 2019). The Dysphagia Handicap

Index (DHI), a 25 item self-rating of a person's physical, emotional and functional swallowing (Silbergleit et al., 2012) was used to screen for markers of swallowing impairment (dysphagia); a minimum or maximum score was not requisite for inclusion.

<u>Baseline measurement of tongue strength</u>

All participants completed a measure of tongue strength using the Iowa Oral Performance Instrument (IOPI) (IOPI Medical, Woodinville, WA). An air-filled, disposable bulb was placed on the anterior surface of the tongue and the participant was instructed to "press your tongue to the hard palate as hard as possible." Participants completed three maximum tongue press measures and a task mean was determined.

<u>Experimental trials</u>

During the study, participants completed six trials of water boluses in four counterbalanced conditions. Liquid bolus volume trials for this experiment were single sips. Bolus conditions were non-cued by cup, cued sip by cup, sip by straw, and sip of carbonated water by cup. Pre-filled graduated cups with a capacity of eight ounces were filled to 100 mL with room temperature water prior to the study onset. Before beginning trials in each condition, participants were instructed to consume, or sip, normally as they would at home. At the onset of the non-cued sip by cup, straw sip, and carbonated sip by cup condition, they were instructed to begin trials when they were ready but provided no additional verbal instructions throughout the condition trials. For the cued sip by cup condition, the participants received instructions to "hold the cup and take a sip when you are told to do so." Participants were verbally instructed to "swallow now" at varying wait times for this condition.

Data analysis

Measurement of liquid bolus volume consumption was completed by two raters. For each trial, the raters were positioned at eye level with the cup on a flat surface. The bolus volume was determined by subtracting the remaining bolus volume in the graduated cup from 100 mL. Trials varying more than 5% between raters were reanalyzed to reach a consensus agreement on liquid bolus volume consumption in mL.

Statistical analyses were conducted using IBM SPSS 24 (Armonk, NY). An independent samples *t*-test was utilized for determining the differences between age groups for natural single sips by cup, and paired sample t-tests were used to determine differences between conditions in participants. A significance level was set at $p<.05$.

RESULTS

Ten older healthy participants (7 females) and 12 younger healthy participants (6 females) completed the study. An additional two participants were screened but did not pass the telephone screening. Participants were TCU faculty, staff, or students due to COVID-19 recruitment limitations. However, one non-TCU participant completed the study during the winter break of the recruitment period following obtainment of TCU's approval to conduct in-person research from the community and completion of an IRB amendment. The older healthy participants spanned in age from 53 to 70 years of age with an average age of 60.4 years. The younger healthy age group had an age range from 20 to 38 years with an average age of 26 years (Table 1).

Table 1

Participant Demographics in Younger and Older Healthy

Criteria	Older Healthy (n=10)	Younger Healthy (n=12)
Age	Mean: 60.4 years Age Range: 53-70 years	Mean: 26 years Age Range: 20-38 years
Sex	M:F : 3:7	M:F : 6:6
Forced Expiratory Volume in 1 s / Forced Vital Capacity (FEV1/FVC)	*M*= 0.836 (SD=0.05)	*M*= 0.8325 (SD=0.06)
Reflux Symptom Index (RSI)	*M*= 2.9 (SD=2.85)	*M*= 2.16 (SD=2.16)
Mini Mental State Examination (MMSE)	*M*=29.1 (SD=1.29)	*M*= 29.75 (SD=0.45)

Note: s= seconds.

Baseline testing for tongue strength using the Iowa Oral Performance Instrument (IOPI) was completed to determine differences between the older healthy and younger healthy groups using an independent samples *t*-test. Older healthy (*M*=59.39 kPa, SD=10.71) and younger healthy (*M*=61.42 kPa, SD=15.83) were not statistically different in tongue strength, *M*= 2.021, 95% CI [-10.27, 14.32], *t* (20) =.343, *p* = 0.735) (Table 2).

Table 2
Tongue Strength (kPa) Mean and Standard Deviation in Older Healthy and Younger Healthy Persons

Group	Mean Max Tongue Press	SD
Older Healthy	59.393	10.710
Younger Healthy	64.416	15.831

Note. SD=standard deviation.

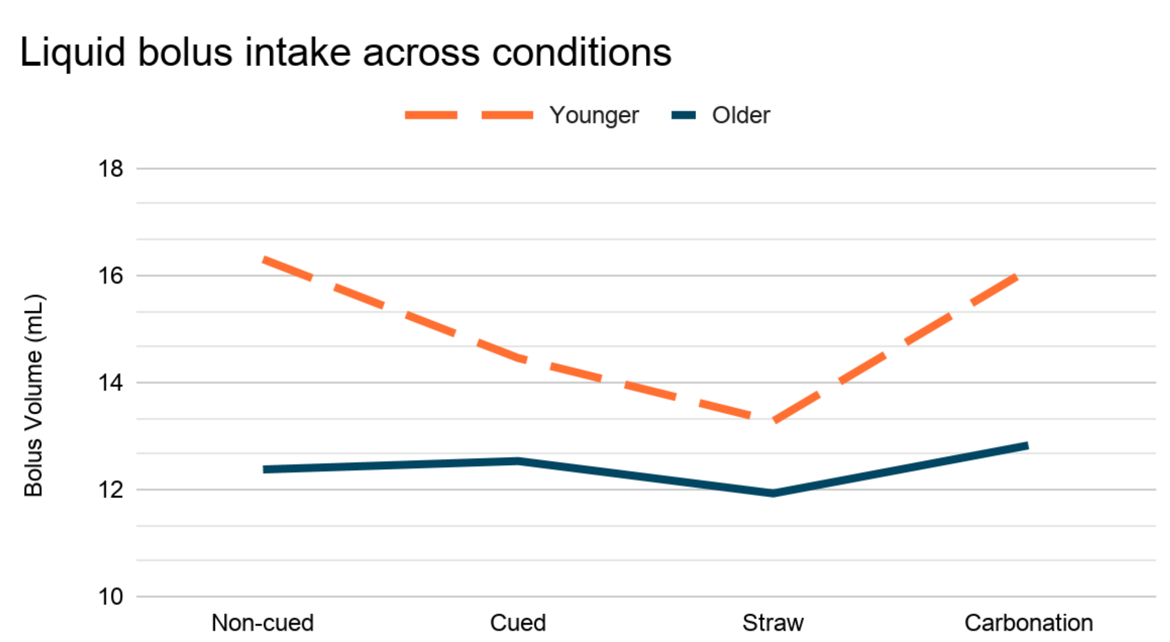
To examine differences in liquid bolus volumes between groups (Table 3), the non-cued single sip liquid bolus group means in younger and older healthy persons were computed and an independent samples t-test was conducted. Older healthy persons' liquid bolus intake (*M*=12.41, SD=8.01) and younger healthy (*M*=15.03, SD=8.62) consumed similar bolus sizes for liquids, *M*=2.62, 95% CI [-.932, 6.17], t (86) = 1.47, p=.146. Figure 1 demonstrates the liquid bolus volumes in the older and younger healthy groups.

Table 3
Bolus Volume (in mL) Mean and Standard Deviation for Older and Younger Healthy Persons by Condition

Condition	Older healthy	Younger Healthy
Non-cued	*M*: 12.37 (SD: 7.00)	*M*: 16.30 (SD: 10.07)
Cued	*M*: 12.53 (SD: 9.02)	*M*: 14.46 (SD: 7.49)
Straw	*M*: 11.93 (SD: 9.53)	*M*: 13.28 (SD: 8.49)
Carbonated	*M*: 12.82 (SD: 7.51)	*M*: 16.11 (SD: 9.00)

A paired samples t-test was conducted to compare liquid bolus volume between conditions: non-cued single sip by cup and cued single sip by cup, non-cued single sip by cup and single sip by straw, and non-cued single sip by cup and single carbonated sip. There were no statistically significant differences in non-cued single sip by cup (M=14.52, SD=8.84) and cued single sip by cup (M=13.58, SD=8.08) (M= 0.935, 95% CI [-1.89, 3.76], $t(21)$= .690, p= 0.498) or non-cued single sip by cup and single sip by straw (M=12.66, SD=8.78) (M=1.85, 95% CI [-1.53, 5.24], $t(21)$= 1.14, p= 0.268). Carbonated sip by cup (M=14.61, SD=8.33) was also not significantly different in liquid bolus volume when compared with non-cued single sip by cup (M= 0.099, 95% CI [-3.21, 3.02], $t(21)$ = -0.066, p= 0.948).

Figure 1



DISCUSSION

Our results found no significant differences between age groups or across conditions in liquid bolus volume size. Older healthy persons tended to consume less liquid (12.37 mL) compared to younger persons (16.30 mL) in a non-cued water bolus by cup. However, neither age group in our study consumed as high of a liquid bolus volume as the majority of the small body of currently published studies. Providing verbal instructions to participants on when to swallow, such as “swallow now”, did not alter bolus volumes in our study. Boluses consumed using a straw yielded the smallest bolus volume for both older healthy (11.93 mL ± 9.53) and younger healthy (13.28 mL ± 8.49). However, straw boluses, along with carbonated boluses, were not significantly different in volume than the non-cued sips by cup.

Previous findings for non-cued bolus volumes ranged from 23.7 mL to 27.2 mL (Lawless et al., 2003) and were found to average 21 mL in another study (Adnerhill et al., 1989). Bennett et al. (2009) reported natural (non-cued) swallows of water at 16 mL which was similar to our natural swallow condition bolus volumes of 12.37 mL for older healthy and 16.3 mL for the younger healthy persons. It is possible that participants were not naïve to our study aims or were impacted by our observations during oral intake. Thus, due to observation phenomena like the Hawthorne Effect, it is possible that our participants changed their behavior once they were aware of observation. A future study should consider the inclusion of a bolus intake task in which participants are blinded to the bolus outcome measurement. It is also reasonable to question whether the sampling only from within the TCU community impacted the findings of the study outcomes as well and whether the current sample is representative of the broader population. Additionally, our sample size (n=22) was significantly smaller than the comparison studies of sixty and one hundred participants and a larger sample size is needed. It is also important to note that the methods in some of the comparison studies varied from our study, including the type of bolus such as sweet juices instead of water; these differences likely influenced findings as well. Further, the lack of inclusion of persons over the age of 65 restricted the ability to compare differences between age groups. A future study examining community-dwelling older healthy persons and younger healthy persons should consider stratifying participant inclusion across age groups. Adnerhill (1989) found differences in bolus volume based on sex with males consuming larger bolus sizes of liquid than females; therefore, consideration of stratifying recruitment based on sex would also be warranted.

Clinical practitioners often provide verbal cues to persons during swallowing tasks, aimed at aiding in swallow safety or improving efficiency. However, cues have been shown to alter a variety of swallowing elements. Daniels et al. (2007) examined the effects of a verbal cue on swallow onset timing and positioning in the oral cavity for trials of a prescribed 10 mL bolus and found that cued swallows yielded significantly shorter swallowing durations and transit times. Although this study found no differences between the cued and non-cued swallows for bolus volume, Bennett et al. (2009) conducted a study administering cold water bolus trials with participants who were blinded to water intake measurement followed by trials in which they were verbally instructed to bolus intake. Their findings of liquid bolus volumes for natural swallows of 16 mL compared to 6 mL for instructed or cued bolus trials supports the idea that the use of cues may alter bolus volumes.

Bolus volume is directly impacted by straw diameter size, with a small straw diameter being associated with smaller bolus volumes (Clark et al., 2014). However, research examining liquid bolus volumes consumed when using a typically sized straw compared with a cup has not been reported. The straws used in this study were plastic and consistently 0.25 inches in diameter. Straw trials averaged 11.92 mL ± 9.53 for older healthy and 13.27 mL ± 8.49 for younger healthy- the smallest bolus volume across conditions for each group. While bolus volumes in straw sips were not different than our non-cued cup sip size, a larger study examining the bolus volumes for straw may have clinical implications. Specifically, persons needing to control their sip size may benefit from a straw delivery method.

Carbonated beverages, which are chemesthetic stimuli causing oral sensation upon presence in the oral cavity, can elicit chemosensory and somatosensory responses. Additionally, carbonation has been shown to reduce incidents of penetration and aspiration, decrease retention of bolus residue in the pharynx, and reduce pharyngeal transit time (Dafiah et al, 2020). The effect of carbonation on bolus volume intake has not been reported in the literature. Although differences between carbonation and non-cued liquid boluses were not present in our study, additional investigation particularly between younger healthy and older healthy should be conducted to determine if carbonation influences bolus size in the older healthy due to the age-related sensory changes that occur in this group. The potential benefits of sensory augmentation with carbonation to the oral cavity on swallowing in persons with impaired swallowing should also be investigated.

CONCLUSION

This pilot study found no significant effect on bolus volume intake for older healthy compared with younger healthy persons. Modulation of bolus delivery method and texture did not yield statistically significant changes in liquid bolus volumes. A larger investigation that stratifies based on age, including above the age of 65 years, and sex would be beneficial to better identify potential effects of aging across conditions. A future direction may also be to examine sensory inputs and their effects on bolus volume in persons with swallowing impairments.

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