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The influence of tongue strength on oral viscosity discrimination acuity

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Abstract

The ability to generate tongue pressures is widely considered to be critical for liquid bolus propulsion in swallowing. It has been proposed that the application of tongue pressure may also serve the function of collecting sensory information regarding bolus viscosity (resistance to flow). In this study, we explored the impact of age-related reductions in tongue strength on oral viscosity discrimination acuity. The experiment employed a triangle test discrimination protocol with an array of xanthan-gum thickened liquids in the mildly- to moderately-thick consistency range. A sample of 346 healthy volunteers was recruited, with age ranging from 12–86 (164 men, 182 women). On average, participants were able to detect a 0.29-fold increase in xanthan-gum concentration, corresponding to a 0.5-fold increase in viscosity at 50/s. Despite having significantly reduced tongue strength on maximum isometric tongue-palate pressure tasks, and regardless of sex, older participants in this study showed no reductions in viscosity discrimination acuity.

Keywords

Deglutition; Deglutition Disorders; Dysphagia; Viscosity; Oral Sensation

Introduction

During the oral phase of liquid swallowing, the tongue holds the bolus in a chamber on its dorsal surface, and applies squeezing forces (pressures) that move the bolus backwards towards the pharynx (Hiemae & Palmer, 2003; Palmer, Hiemae, Matsuo, & Haishima, 2007). Several studies suggest that the amplitude and time-scale of tongue pressure application vary according to bolus viscosity (i.e., resistance to flow) (Nicosia et al., 2000; Poudroux & Kahrilas, 1995; Steele et al., 2015; Steele, Molfenter, Peladeau-Pigeon,

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Ethical statements

This study received ethics approval from the research ethics board of the University Health Network, Toronto. All participants provided written informed consent prior to participation. The author has no conflicts of interest to disclose.

Polacco, & Yee, 2014; Youmans, Youmans, & Stierwalt, 2009). It has been suggested that the tongue may be acting as an oral rheometer during the process of applying pressure to a bolus (Nicosia & Robbins, 2001), such that sensory information about bolus flow properties is collected. Assuming that this is true, the motor ability of the tongue to apply pressure might be critical to the challenge of correctly appraising bolus viscosity. Individuals with age- or disease-related tongue weakness might experience difficulty generating sufficient tongue-palate pressure to initiate bolus flow or to shear the bolus. In these cases, even when oral sensory function is otherwise intact, tongue weakness might be expected to lead both to a blunted ability to detect differences in liquid viscosity and to difficulties in modulating tongue propulsive forces to match bolus flow properties. In this study, we were interested to explore differences in viscosity discrimination acuity as a function of tongue strength. A previous study (Steele, James, Hori, Polacco, & Yee, 2014) failed to find any differences in viscosity discrimination between two cohorts of healthy adults aged 18–39 and 60–87, respectively. The testing protocol involved an array of five liquids thickened with increasing concentrations of xanthan-gum to viscosities in the nectar- to honey-thick range of the National Dysphagia Diet (Felt, 1999), which corresponds to Levels 2 and 3 (mildly-thick and moderately-thick) on the International Dysphagia Diet Standardisation Initiative Framework (Cichero et al., 2016). Steele et al. reported that both cohorts were able to reliably detect a 0.38-fold relative increase in xanthan-gum concentration with 95% confidence intervals ranging from detection thresholds of 0.35- to 0.41-fold (Steele, James, et al., 2014). This translated to detection of a 0.67-fold increase in apparent viscosity at a shear rate of 50/s.

Tongue strength was, however, not explored as a factor in the Steele et al. (Steele, James, et al., 2014) study of viscosity discrimination. Several recent studies concur that tongue strength declines in healthy aging, particularly after age 70 (Adams, Mathisen, Baines, Lazarus, & Callister, 2013; Clark & Solomon, 2014; Crow & Ship, 1996; Fei et al., 2013; Nicosia et al., 2000; Robbins, Levine, Wood, Roecker, & Luschei, 1995; Utanohara et al., 2008; Vanderwegen, Guns, Van Nuffelen, Elen, & De Bodt, 2013; Vitorino, 2010; Youmans & Stierwalt, 2006; Youmans et al., 2009). Older women are reported to have reduced tongue strength compared to men (Adams et al., 2013; Adams, Mathisen, Baines, Lazarus, & Callister, 2014; Vanderwegen et al., 2013). Tongue strength is commonly measured by requiring a person to use the tongue to compress an air-filled bulb against the palate using a device known as the Iowa Oral Performance Instrument (IOPI; IOPI Medical, Redmond, WA). The amount of air pressure that is squeezed out of the bulb during this task has been shown to relate directly to the force applied by the tongue (Poudroux & Kahrilas, 1995). The measurement that is typically reported as a measure of tongue strength is the one-repetition maximum isometric pressure, namely the highest pressure recorded across 3 to 5 repetitions of a maximum effort tongue press.

The purpose of this study was to replicate and extend the previous work reported by Steele et al. (Steele, James, et al., 2014), and specifically to determine whether age-related reductions in tongue strength are correlated with oral sensory discrimination of differences in liquid viscosity in healthy adults. We formulated the following research questions:

- 1a)** Does tongue strength decline in healthy adults over the age of 70?

- 1b)** Do healthy women show a greater decline in tongue strength above age 70 than men?

Given previous literature, we expected that the answer to both of these questions would be yes.

- 2)** Does reduced tongue strength lead to poorer viscosity discrimination acuity?

We hypothesized that age-related differences in viscosity discrimination would not be seen, consistent with the results previously reported by Steele et al. (Steele, James, et al., 2014). However, given the premise that tongue weakness might lead to blunter viscosity discrimination ability, we hypothesized that any evidence in this regard would be most clearly seen in older female participants.

Materials and Methods

This cross-sectional observational study received human subjects approval from the local institutional research ethics board. All participants provided written informed consent prior to participation. Data were collected either in the exhibit area of a public science museum or by appointment in a research laboratory located inside a rehabilitation hospital. The larger study protocol comprised three different sub-experiments: 1) an exploration of age- and sex-related variations in tongue pressure generation for strength and saliva swallowing tasks (Peladeau-Pigeon & Steele, 2017); 2) the current experiment exploring variations in liquid viscosity discrimination; and 3) an exploration of variations in oral stereognosis due to age, sex and genetic taste status. This article focuses on the liquid viscosity discrimination portion of the protocol.

Participants

Three hundred and forty-six healthy volunteers (164 men, 182 women) consented to participate in the study. Due to the primary location of the study in a public science museum, we permitted participation by individuals as young as 12. The age range of the sample was from 12–86 years (mean: 39.09, standard deviation: 18.04). All participants completed a brief intake interview to confirm eligibility. The exclusion criteria matched those from the previous Steele et al. study (Steele, James, et al., 2014): individuals were excluded if they reported previous or current dysphagia, stroke, neurodegenerative disease, gastrointestinal disease, chronic sinus infections, type I diabetes, head and neck cancer, radiation therapy for head and neck cancer, major head and neck surgery, regular alcohol consumption in excess of 1 drink/day, cigarette smoking (in the past 12 months), use of recreational drugs or use of prescription drugs causing oral dryness, drowsiness or alterations in taste or smell. Individuals who wore full upper dentures were accepted into the study, provided that they were willing to remove their dentures during data collection. Denture wearing was not recorded as a parameter for the analysis.

Data Collection

a) Tongue Strength Reference Task—The experiment began with measurements of tongue strength during an anterior isometric tongue-palate pressure task (AMAX). Tongue pressures were measured in kilopascals (kPa) at a sampling frequency of 30 Hz using the

Iowa Oral Performance Instrument (IOPI; IOPI Medical, Redmond, WA). The digitized IOPI signal was displayed on a laptop computer that was visible to the participants. Participants were instructed to place the air filled bulb just behind their front teeth and to lift their tongue in order to squeeze the bulb against the roof of their mouth as hard as possible. Participants were given an opportunity to practice both regular effort and maximum effort tongue-palate presses before performing the actual experimental task. The highest peak pressure produced across a series of 5 repeated AMAX tasks was taken as the participant's maximum tongue strength measure.

b) Viscosity Discrimination Acuity—The viscosity discrimination task was an abbreviated version of the protocol previously reported by Steele et al. (Steele, James, et al., 2014). Triangle tests were performed using samples of red (raspberry-flavour) or green (lime flavour) water, pre-thickened to 5 different viscosities between 190 and 390 mPas (measured at 50/s) with xanthan-gum in concentrations ranging from 0.5% to 0.87%. Sucrose concentration was held constant across the stimuli to limit any confounding influence of perceived differences in sweetness. Samples were kept in a refrigerator at 4 degrees Celsius until immediately before use. For each “trial” in the triangle test protocol, participants were handed a loaded teaspoon containing a liquid sample. They were instructed to take the sample in their mouth, press it towards the palate with their tongue to appraise its thickness, then expectorate the sample. This process was then repeated for two additional samples. All three samples in a trial were of the same colour and flavour. One sample in each trial had a different xanthan-gum concentration from the other two. The task was to identify which sample was different (i.e., thinner or thicker).

In the previous Steele et al. study (Steele, James, et al., 2014), the protocol involved 20 triangle test trials. Post-hoc analyses of data from that study (Steele, James, et al., 2014) revealed that discrimination acuity stabilized rapidly over the first 7 trials, and that the 95% confidence interval for discrimination accuracy for trial 7 overlapped with and contained the 95% confidence intervals for trials 10–20 (see Figure 1). Based on these data, a decision was made to limit the current data collection protocol to 7 trials of triangle test stimuli. Twelve different sequences of triangle testing were developed, with balanced inclusion of 8 different degrees of xanthan-gum concentration contrast, expressed as the difference in xanthan-gum concentration divided by the concentration of the thinner stimulus in the trial (increases of 6%, 9%, 16%, 26%, 30%, 34%, 38% and 50%). The 67% concentration difference that was tested in the Steele et al. study was omitted, due to the superior detection accuracy seen with that contrast in the original study (Steele, James, et al., 2014). Participants were randomly assigned to one of the 12 triangle testing sequences and to a single liquid flavor (either raspberry or lime). The average xanthan-gum concentration difference of correct responses after 7 triangle test trials gave the individual's Mean Xanthan-Gum Concentration Discrimination Acuity Score (MXCDA).

Analysis

Statistical analyses were performed in SPSS version 24 (IBM SPSS Statistics, IBM, Armonk, NY, NY) using an alpha criterion of 0.05. The analysis proceeded in a stepwise fashion as follows:

1. To address research questions 1a and 1b (i.e., age-group and sex differences in tongue strength), the data for maximum isometric pressure were plotted as a function of age-group and sex. A fully factorial 2-way univariate analysis of variance (ANOVA) with between participants factors of age-group (decade) and sex was performed. Post-hoc testing for pairwise differences was performed using Sidak testing. Cohen's d measures of effect size were also calculated.
2. Based on the results for questions 1a, it was decided that further post-hoc investigations would be conducted using binary categorizations of tongue-strength and age. Tongue-strength was reduced into a categorical measure (weak vs. within normal range), with a boundary of one standard deviation below the sample mean for maximum isometric tongue pressure (i.e., 40.51 kPa) used to delineate these two categories. This value corresponds to the clinical cut-off of 40 kPa that has been used in previous clinical trials research for determining whether or not a patient exhibits tongue weakness (Steele et al., 2016). Age-group was similarly reduced to a categorical measure (under 70 vs. 70 or older). Participants were then grouped according to the four combined tongue strength X age-group categories: 1) under 70 and weak; 2) under 70 with normal tongue strength; 3) 70 or older and weak; 4) 70 or older with normal tongue strength.
3. Frequencies for correct triangle test responses were computed overall and by tongue-strength/age-group and sex.
4. Descriptive statistics for xanthan-gum discrimination acuity were calculated by age-group and sex.
5. To explore the relationship between tongue strength and MXCDA, a scatter plot was generated and Pearson's product moment correlations and R^2 values were calculated.
6. A fully factorial 2-way univariate ANOVA with between-participants factors of sex and the combined tongue strength/age-group category was then performed to identify any differences in xanthan-gum concentration discrimination acuity.

Results

Figure 2 shows the distribution of maximum isometric pressure scores by participant age. Descriptive statistics for measures of anterior maximum isometric tongue pressure by sex and age-group can be found in Table 1. Significant main effects were found both for age-group (decade) and sex. Individuals in the oldest age-group (70 and older) had significantly lower tongue strength than all other age-groups [$F(6, 332) = 3.14, p = 0.005$]. This result had a large effect size (Cohen's $d = 0.87$). Across the entire sample, female participants had significantly lower tongue strength than male participants [$F(1, 332) = 5.47, p = 0.02$]. This result had a small effect size (Cohen's $d = 0.27$). There was no significant decade by sex interaction.

The frequencies of correct triangle test responses are shown by xanthan-gum concentration difference in Table 2. No obvious trends are noted with respect to reduced accuracy for the

older female participants or those classified with tongue strength below 40.51 kPa. Descriptive statistics for mean xanthan-gum concentration discrimination acuity scores can be found in Table 3. Figure 3 illustrates the association between mean xanthan-gum concentration discrimination acuity and maximum isometric tongue pressure. Overall, there was no significant correlation between tongue strength and viscosity discrimination acuity ($R = 0.08$). However, given the significant age-group and sex differences seen in tongue pressure, further post-hoc investigation using the combined tongue strength/age-group categories was pursued. No significant differences in viscosity discrimination were found for main effects or interactions of the combined tongue strength/age-group factor or sex.

Discussion

These data suggest that age-related reductions in tongue strength do not impact an older person's ability to detect small differences in viscosity for mildly-thick and moderately-thick liquids prepared using increasing concentrations of xanthan-gum. On average, the participants in this study were able to detect a 0.29-fold increase in xanthan-gum concentration (95% confidence interval: 0.27- to 0.31-fold). Translating these results to viscosity, measured at 50/s, participants in this study were able to detect, on average, a 0.5-fold increase in viscosity (95% confidence interval: 0.49- to 0.52-fold). Overall, response accuracy was similar to the results seen in Steele et al.'s original study (Steele, James, et al., 2014). There was no evidence of age-related reductions in oral sensory viscosity discrimination acuity.

This finding corroborates the previous finding of stable viscosity discrimination acuity with advancing age in healthy adults (Steele, James, et al., 2014). In fact, the current findings were actually better (i.e., more precise) than the 0.38-fold xanthan-gum concentration and 0.67-fold viscosity discrimination acuity results previously reported using a longer testing protocol (Steele, James, et al., 2014). It may be that fatigue related to the cognitively challenging task of focusing on liquid viscosity across a larger number of triangle test trials contributed to less accurate detection and higher acuity thresholds in the previous study.

It is of clinical importance to show that reductions in tongue strength do not appear to impact viscosity discrimination acuity. Although different nerves subserve sensory function in the oral cavity (cranial nerves V, VII, IX and X) and tongue motor function (XII), the possibility that tongue weakness might result in difficulties generating the necessary pressures to initiate or modulate bolus flow led to the study premise that the oral ability to detect differences in viscosity might be blunted by tongue weakness. The current results provide further support that oral viscosity discrimination does not appear to decline either with age or with age-related reductions in tongue strength in healthy adults. Consequently, any deficits that are detected in oral sensory function related to detecting bolus viscosity should be viewed as unusual and of potential clinical relevance in older adults. Nevertheless, as with Steele et al.'s study (Steele, James, et al., 2014), caution should be exercised when generalizing these discrimination acuity results to liquids that fall outside the range of consistencies tested, or to liquids prepared with different thickening media.

A particular limitation of the current study lies in the likelihood that the liquids tested require relatively little tongue strength in order for flow to be initiated, such that any reductions in maximum tongue strength measures had no impact on the tongue pressures required to initiate bolus propulsion or modulate bolus flow. The tongue strength measures in the participants aged 70 and older in this study were significantly lower than those seen in participants aged 69 and younger, but they were still greater than the values reported to be used in swallowing (Fei et al., 2013; Nicosia et al., 2000; Steele, Molfenter, et al., 2014; Youmans et al., 2009).

A further limitation, which must be noted, is the relatively smaller sample size for the subgroup of participants aged 70 and older (which spanned a 16-year age-range in contrast to the younger decade-defined age-groups), and particularly the smaller number of women who were recruited in this age group. This reflects the challenges inherent in finding older research participants who are free from any of the conditions specified in the exclusion criteria.

In conclusion, this study corroborates previous evidence that healthy adults are able to discriminate quite small differences in the viscosity of xanthan-gum thickened liquids. Given a 7-set triangle test protocol, participants were able to reliably detect 0.5-fold increases in viscosity in the 190–390 mPa.s @50/s range. There was no evidence that age-related reductions in tongue strength impacted viscosity discrimination with these liquids.

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Practical Applications

In this article, the relationship between tongue strength and the ability to discriminate small differences in liquid viscosity during oral processing is explored. Given that tongue strength declines with age in healthy adults and is also reduced in individuals with dysphagia, it is interesting to determine whether reduced tongue strength might contribute to difficulties in evaluating liquid viscosity during the oral stage of swallowing. Using an array of mildly to moderately-thick xanthan-gum thickened liquids, this experiment failed to find any evidence that reductions in tongue strength influence oral viscosity discrimination acuity.

Figure 1.

Means and confidence intervals for xanthan-gum concentration discrimination acuity scores across accurately performed triangle test trials in a previous study by Steele et al. (Steele, James, et al., 2014).

Post-hoc analysis of means and 95% confidence intervals for Mean Xanthan-Gum Concentration Discrimination Acuity (MXCDA) scores across triangle test sets in the Steele et al. study (Steele, James, et al., 2014), with moving average, showing stability after trial 10, and overlap in the confidence intervals of trial 7 and trials 10–20 (shaded area).

Figure 2.
Scatterplot for maximum isometric tongue-palate pressures by age.
The data show lower tongue strength in adults aged 70 and older, which was confirmed in the ANOVA results summarized in Table 1.

Figure 3.

Scatterplot showing the relationship between xanthan-gum concentration discrimination acuity and tongue strength

There was no significant correlation between viscosity discrimination acuity and tongue strength.

Table 1
Descriptive Statistics for Maximum Isometric Tongue-Palate Pressure (in kPa) by age-group and sex

Decade	Sex (N)	Mean	Standard Deviation	95% Confidence Interval	
				Lower boundary	Upper boundary
12–19	Female (N = 32)	50.6	15.28	48.36	52.85
	Male (N = 27)	52.72	16.01	50	55.45
	Both sexes	58.99 ^a	14.03	55.33	62.65
20–29	Female (N = 32)	47.99	12	46.12	49.87
	Male (N = 28)	52.88	16.25	50.29	55.47
	Both sexes	54.84	14.79	51.02	58.86
30–39	Female (N = 29)	48.85	13.71	46.56	51.14
	Male (N = 31)	59	17.6	56.13	61.87
	Both sexes	58.15 ^a	15.91	54.04	62.26
40–49	Female (N = 34)	53.14	14.52	51.06	55.22
	Male (N = 29)	51.6	17.21	48.87	54.33
	Both sexes	58.18 ^a	15.47	54.28	62.08
50–59	Female (N = 26)	45.08	13	42.73	47.42
	Male (N = 25)	52.13	17.64	48.78	55.48
	Both sexes	54.95	16.35	50.35	59.55
60–69	Female (N = 22)	46.95	11.78	44.48	49.41
	Male (N = 14)	48.09	18.05	43.62	52.57
	Both sexes	52.54	15.45	47.32	57.77
70 and older	Female (N = 7)	35.43	10.93	31.35	39.51
	Male (N = 10)	40.96	13.77	37.04	44.87

Decade	Sex (N)	Mean	Standard Deviation	95% Confidence Interval	
				Lower boundary	Upper boundary
Pooled Subgroup: 10–69	Both sexes	43.79 ^a	12.01	37.61	49.96
	Both sexes	56.59 ^a	15.36	54.93	58.26
Entire Sample	Female (N = 182)	52.36 ^b	13.77	49.84	54.88
	Male (N = 164)	56.59 ^b	16.87	54.08	59.11
	Both sexes	55.96	15.45	54.33	57.6

^aPairwise comparisons showed significantly lower tongue strength ($p < 0.05$) for participants aged 70 and older compared to participants aged 12–19, 30–39, 40–49 and the pooled subgroup of participants aged 12–69.

^bPairwise comparisons showed significantly lower tongue strength ($p < 0.05$) for female participants.

Frequency of correct viscosity discrimination responses for the different degrees of xanthan-gum concentration contrast included in the triangle test protocol, shown by age-group, tongue-strength group and age.

Table 2

Xanthan Concentration Increase (%)	% Correct					
	Age 12-69			Age 70- and older		
	Tongue Strength		40.51 KPa	Tongue Strength <40.51 KPa		Total
	Female	Male		Female	Male	
6%	40%	33%	33%	0%	40%	37%
9%	41%	35%	0%	0%	40%	38%
16%	45%	43%	17%	75%	40%	46%
26%	41%	30%	33%	25%	75%	35%
30%	43%	50%	45%	33%	25%	44%
34%	44%	44%	100%	75%	43%	46%
38%	50%	71%	58%	50%	53%	55%
50%	55%	53%	67%	50%	86%	55%

Descriptive Statistics for Mean Xanthan-gum Concentration Discrimination Acuity by age-group, tongue-strength group and sex

Table 3

Age-Group	Tongue-Strength Group	Sex	Mean	Standard Deviation	95% Confidence Interval	
					Lower Bound	Upper Bound
Under 70	Weak (<40.51 kPa)	Male	0.28	0.06	0.25	0.31
		Female	0.25	0.07	0.22	0.28
	Within Normal Range (40.51 kPa)	Male	0.27	0.09	0.26	0.29
		Female	0.28	0.08	0.26	0.29
70 and older	Weak (<40.51 kPa)	Male	0.25	0.11	0.00	0.53
		Female	0.33	0.12	0.03	0.63
	Within Normal Range (40.51 kPa)	Male	0.31	0.05	0.27	0.36
		Female	0.31	0.08	0.18	0.44
Grand Mean			0.29	0.08	0.27	0.31