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Age and strength influences on lingual tactile acuity

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Abstract

Sensory function during the oral processing of liquids is thought to play a key role in informing the tailoring of swallowing motor behaviours to the flow characteristics of the bolus. In addition to taste receptors, the mouth and tongue house trigeminal nerve receptors that support the sensory detection of bolus size, shape (stereognosis), mass, temperature and movement. Recent studies suggest that healthy adults lose tongue strength with advancing age. However, little is known about changes in the sensory function of the tongue attributable to age, or associated with reductions in strength. In this study, we explored lingual tactile acuity in healthy young and older adults, and measured the relationship between tactile acuity and measures of tongue strength. The results showed an age-related reduction in lingual tactile acuity that was not explained by variations in tongue strength.

Practical Applications—Sensory motor interactions are a topic of interest in understanding the processing activities that take place in the mouth during eating and swallowing. In this paper, we explore a test of sensory acuity in the mouth, in which the tongue is used to “read” embossed letters on Teflon strips. Our questions were to determine whether sensory acuity for this task declines with age, or with age-related reductions in tongue strength. We determined that older people perform this task with less accuracy, suggesting some changes in oral sensory function with age. However, these changes were not related to tongue strength. The findings suggest that strength does not play a major role in the kind of sensory discrimination task tested in this study.

Keywords

Oral sensation; stereognosis; tongue; pressure; spatial resolution acuity

Introduction

The tongue plays a key role in both sensory and motor aspects of the oral stage of swallowing, particularly for preparing, forming, manipulating, and transporting the bolus.

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Sensory receptors in the mouth, including those on the surface of the tongue, are thought to transmit information about bolus characteristics to higher cortical centers (e.g., Brodmann's areas 3, 5 and 7 representing primary sensory, somatosensory and somatosensory association cortex), so that the motor program for swallowing can be tailored appropriately to properties such as viscosity (Shama and Sherman, 1973). It is therefore of interest to understand the sensory function of the tongue for tasks that may be relevant for detecting differences in the flow characteristics of swallowing, in particular, sensory tasks that require motor behaviours of the tongue to explore, squeeze or move a bolus in order to ascertain its flow properties. Trigeminal nerve receptors in the mouth are capable of detecting both static and dynamic characteristics of items placed in the mouth, such as shape (stereognosis), size, volume, mass, location, temperature, two-point discrimination, and flow or movement (Calhoun *et al.*, 1992; Yekta *et al.*, 2010). Thermal, somesthetic and stereognostic sensory functions are reported to remain robust in healthy aging, at least up to age 80 (Calhoun *et al.*, 1992). Similarly, the ability to discriminate differences in liquid viscosity in the mouth appears to remain intact up until age 80, with possible reductions in later decades (Smith *et al.*, 2006; Steele *et al.*, 2014). Conversely, recent studies confirm that tongue strength declines with age in healthy people, beginning as early as age 60 (Nicosia *et al.*, 2000; Utanohara *et al.*, 2008; Youmans *et al.*, 2009; Tamine *et al.*, 2010; Vanderwegen *et al.*, 2012; Fei *et al.*, 2013; Steele, 2013). Individuals with maximum isometric tongue-palate pressure measurements below 300 mmHg or 40 KPa also report greater difficulty swallowing thick consistency liquids with ease (Alsanei and Chen, 2014).

In 1999, Essick and colleagues described a protocol for detecting the spatial resolution acuity of tactile discrimination by the tongue (Essick *et al.*, 1999). In this task, which involves motor exploration of sensory stimuli by the tongue, blindfolded participants are asked use their tongue to “read” and identify upper case non-seraph letters of the alphabet that are embossed on Teflon strips. The letters vary in size (equivalent to 10, 12, 18, 21, 28, 30, and 34-point fonts), and detection accuracy is probed, beginning with medium-sized letters. The test begins with the examiner randomly selecting a strip containing a medium size letter from a set of 7 possible letters (A, I, J, L, T, U, and W). When a correct response is obtained, the examiner proceeds to select the next strip randomly from the letter set that is one step smaller in size; conversely, incorrect responses lead to a stepwise increase in letter size. When response accuracy changes between consecutive presentations (i.e., a correct response followed by an incorrect response, or vice versa), this is classified as a “response reversal”. The mean letter height across 7 reversals, which requires approximately 40 trials, is used as the index for accurate identification 50% of the time. If, for example, a testing sequence yielded a series of A demonstration study in 83 healthy young women found significantly better spatial resolution in genetic supertasters compared to non-tasters, which was explained based on fungiform papillae density (Essick *et al.*, 2003).

To our knowledge, differences in spatial resolution acuity as a function of age or tongue strength have not previously been described. Given that the tongue must move upwards towards the teflon strip, and that a certain amount of pressure must be applied by the tongue during the exploration of the embossed letter, we were curious to determine whether tongue strength contributes to differences in task performance. The purpose of this study was to fill

this gap in knowledge. Our hypothesis was that individuals with reduced tongue strength would exhibit poorer spatial resolution acuity overall. If confirmed, this hypothesis might also point to the possibility that ability to detect small differences in fluid viscosity or bolus texture might be poorer in individuals with reduced tongue strength. Further, given the expectation that reduced strength would be a characteristic of measures collected in older participants, we expected to find an age-group X strength interaction, such that those participants with the combination of advanced age and reduced tongue strength would show the poorest spatial resolution acuity.

Materials and Methods

Participants

A sample of 78 healthy adults was recruited to participate in the study. These individuals were divided into two gender-balanced age-groups: 39 individuals under age 40 (mean age: 26; SD: 4), and 37 individuals over age 60 (mean age: 70; SD: 7). Individuals with a history of dysphagia, gastrointestinal disease, neurological disease and major surgery to the head and neck were excluded. Exclusion criteria also included diabetes and current smoker status (within 1 year), given the possibility that these conditions might influence oral sensory function (Dessirier *et al.* 2000; Schiffman *et al.*, 2002; Pepino and Mennella, 2007). The study was approved by the local institutional research ethics board.

Data collection

Tactile discrimination acuity was measured using the Spatial Resolution Acuity test described by Essick *et al.* (1999). Figure 1 illustrates the sequence of testing using this protocol, in which the participant was instructed to place a teflon strip on which there was an embossed non-serif capital letter of the alphabet in their mouth, resting up against the alveolar ridge with the embossed side facing downwards, and to search the embossed area of the strip with their tongue tip in order to identify the letter. Seven letters were included in the test array, (A, I, J, L, T, U, and W). The letter strips were arranged letter-side down on a tray in rows organized by letter size (i.e., 2.5, 3, 4, 5, 6, 7 or 8 mm). The protocol began with the examiner randomly selecting a letter of medium size for presentation (i.e., 5 mm). If an error in letter naming was observed, the researcher moved up one step in letter size (e.g., from 5 mm to 6 mm), and randomly selected a new letter strip for the next presentation. Alternatively, if the first letter was correctly identified, the researcher moved down one step to randomly select a letter of the preceding letter size for the next presentation (e.g., from 5 mm to 4 mm). This procedure continued until 8 reversals of response type were obtained (e.g. correct changing to incorrect on the next presentation). The mean letter height for the correct responses until the 8th response reversal was then calculated as the person's spatial resolution acuity score.

Tongue strength was measured using the lingual pressure module of the KayPentax Swallowing Signals Lab. This system uses a soft silicon strip housing 3 circular air-filled pressure bulbs, each 1.3 cm in diameter and 5 mm in height, spaced 8 mm apart and calibrated to hold 100 kPa of air in each sensor. As shown in Figure 2, this strip is glued along the midline of the palate such that the anterior sensor is located on the alveolar ridge,

just behind the teeth, while the posterior sensor is located at the back of the palate, close to the junction of the hard and soft palates; the middle sensor is located halfway between these two positions. When the tongue contacts the roof of the mouth and compresses a sensor, air from that sensor is displaced into the tubing running from the sensor to a control box, and is registered as an applied pressure. In this experiment, continuous pressure traces from the 3 sensors were registered up to a ceiling of 750 mmHg (i.e., 100 kPa), and displayed on a monitor. A waveform indexing algorithm was applied to the pressure data to identify the onset (departure from baseline), peak (maximum value) and offset (return to baseline) at the anterior, middle and posterior palate. From these values, the difference between the lowest onset or offset pressure (typically zero) and the highest peak pressure measured across the 3 sensors was calculated as the amplitude for each task repetition. Participants were asked to produce a series of 5 repeated maximum isometric pressure tasks. The task instruction was to “squeeze the air out of the pressure bulbs as hard as possible using your tongue”; there was no instruction to prolong the duration of the maximum pressure activity. The highest amplitude obtained across this series of maximum effort tasks was used as the participant’s tongue strength measure.

Analysis

A series of statistical analyses were conducted using IBM SPSS 22.0 using an alpha criterion of $p = 0.05$. First, descriptive statistics for tongue strength were calculated, as listed in Table 1. A univariate analysis of variance (ANOVA) confirmed the presence of significantly reduced tongue strength in the mature cohort compared to the younger participants [$F(1, 74) = 11.45, p = 0.001$]. However, inspection of the data by age (see Figure 3) revealed considerable overlap in the data by age-group, with some older participants displaying good tongue strength, and conversely some younger participants displaying relatively poor tongue strength. This prompted us to divide participants into two groups defined by the boundary between the 1st and 2nd quartiles for mean isometric tongue strength (i.e., above or below 380 mmHg). An exploratory ANOVA confirmed significant differences in tongue strength between these two tongue strength groups [$F(1, 72) = 67.37, p < 0.001$], with no significant differences as a factor of participant age-group or sex.

The main analysis then proceeded using univariate ANOVAs to identify differences in the dependent variable of spatial resolution acuity as a function of between participant factors of age-group (young; mature), and tongue strength group (first quartile; above first quartile). Separate ANOVAs were run for spatial resolution acuity values after the 4th, 5th, 6th, 7th and 8th response reversals. Pairwise comparisons were further explored using Sidak tests, and effect size was calculated using the Cohen’s d statistic, which classifies effects as small and medium for values up to 0.5 and 0.8, respectively and large for values over 0.8 (Kotrlík and Williams, 2003).

Results

Figure 4 illustrates the trend in spatial resolution acuity across the number of response reversals in the protocol for participants by age-group. It can be seen that for both groups, spatial resolution accuracy improves (i.e., becomes lower) with successive reversals, and

that overall the values are higher (i.e., less accuracy in discrimination) for the older participants. For the younger subgroup, values appear to stabilize after approximately 3 reversals, while it appears to take longer to achieve stable values in the mature cohort, who require approximately 5 reversals for optimum performance.

Table 2 shows the results of the ANOVAs performed for spatial resolution acuity after 4, 5, 6, 7 and 8 reversals. The results clearly show that the observed differences are better explained by participant age, rather than by tongue strength, with the interaction between these factors being non-significant. Effect sizes for the age-group comparison were medium for all ANOVA tests, with the comparison achieving statistical significance at the $p = 0.05$ level for spatial resolution acuity scores after 6 and 7 reversals, and falling close to the p -value criterion in all remaining cases.

Discussion

This study illustrates an age-related reduction in lingual tactile acuity using the Essick Spatial Resolution Acuity test in healthy participants in two age groups (under 40; over 60 years of age). On average, the threshold for 50% accurate detection of the identity of embossed non-serif capital alphabetic letters was a size of 5.55 mm after 8 response reversals. This compared to a threshold of 4.8 mm in the younger participant cohort. Additionally, although the original study by Essick *et al.* (2003) recommended that 8 response reversals were required to achieve saturation, in this study we found that response accuracy stabilized and saturation was achieved faster in the younger cohort. Age-group differences in spatial resolution consistently displayed a medium effect size after 4 response reversals. The extent to which this result reflects sensory versus cognitive performance issues is not clear.

We had expected to see age-related reductions in tongue strength in our participants based on measurements of maximum isometric tongue pressure. At a group level, this hypothesis was confirmed, however, as reported in other recent studies (Steele, 2013; Youmans, *et al.*, 2009), this sample of healthy adults included some older individuals with good tongue strength and also some younger individuals with relatively weaker tongue strength, such that age alone was not a reliable predictor of tongue strength. Consequently, a different grouping based on the upper 1st quartile boundary for tongue strength measures for the whole sample was decided to be a more appropriate way to divide participants into those with stronger versus weaker tongue strength (see Figure 3). The data showed no significant differences in measures of spatial resolution acuity based on this classification of tongue strength, and no interactions between age-group and tongue strength classification.

The data suggest that tongue strength, at least as measured during maximum isometric tasks, does not factor heavily into the stereognostic task of discriminating and identifying an alphabetic letter shape using the tongue. That is, even individuals with relatively poorer tongue strength were able to perform this task. This result is reminiscent of results regarding the tongue strength used in liquid swallowing tasks, which suggest that the strength used for bolus propulsion is typically below 30% of maximum isometric strength values (Nicosia *et al.*, 2000; Fei *et al.*, 2013). Whether differences in performance on the Essick Spatial

Resolution Acuity test are associated with differences in intra-oral viscosity discrimination or with differences in tongue behaviours during swallowing are questions to be explored in future studies.

We conclude that performance on the Essick Spatial Resolution Acuity test does decline with advanced age in healthy adults, but that performance accuracy does not appear to be related to tongue strength. *Lingual tactile acuity*

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Figure 1.
Illustration of the Spatial Resolution Acuity test protocol

Figure 2.
Kay-Pentax Digital Swallow Workstation Lingual Pressure Measurement Sensor Strip

Figure 3.

Distribution of tongue strength measures (in mmHg) by participant age.

Although the group means for tongue strength are significantly lower in the older participants at a p -value < 0.05 , the distribution of scores suggests that a more appropriate way to classify participants based on tongue strength is to divide them into participants with strength above or below the upper boundary of the 1st quartile for the entire sample, shown by the dashed line at a value of 380 mmHg.

Figure 4.

Age-group differences in lingual tactile acuity after 4–8 response reversals on the Essick Spatial Resolution Acuity test.

Descriptive statistics for maximum isometric tongue pressure measures (in mm Hg) by subgroup (below or above the 1st quartile) and the entire sample.

Table 1

Group	Mean (mm Hg)	95% Confidence Interval		Range	
		Lower Boundary	Upper Boundary	Lower Boundary	Upper Boundary
1st (lowest) Quartile	301	275	327	187	379
2nd Quartile and higher	508	483	532	383	749
Entire sample	456	428	484	187	749

ANOVA results (*F*-statistic, *p*-value) for differences in spatial resolution acuity as a function of tongue strength and age-group after 4–8 reversals on the Essick Spatial Resolution Acuity test.

Table 2

	Tongue Strength		Age		Pattern of effect	Effect size (<i>d</i>)
	<i>F</i> (1, 72)	<i>p</i> -value	<i>F</i> (1, 72)	<i>p</i> -value		
4th reversal	1.61	0.21	3.73	0.06	Mature > Young	0.53 (medium)
5th reversal	1.74	0.19	3.7	0.06	Mature > Young	0.55 (medium)
6th reversal	1.08	0.3	4.5	0.04*	Mature > Young	0.55 (medium)
7th reversal	1.43	0.24	4.12	0.05*	Mature > Young	0.58 (medium)
8th reversal	2.24	0.14	3.32	0.07	Mature > Young	0.64 (medium)

* statistically significant at a *p*-value of 0.05