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Comparative tactile sensitivity of the fingertip and apical tongue using complex and pure tactile tasks

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ABSTRACT

Both the tongue and fingertip are highly tactile tissues relevant in texture perception, but work comparing relative sensitivity to elucidate potential differences in stimulus processing is limited. Presently, the acuity of the tongue and fingertip were compared using a series of tactile acuity tasks. We hypothesized the tongue would show superior acuity regardless of stimuli due to an absent epidermal barrier and its involvement in many high-sensitivity behaviors (e.g. eating, speaking). Acuity was determined using three different tests, two "purely-tactile" just noticeable difference (JND) tasks (punctate pressure and roughness sensitivity) and a more-complex, stereognostic letter-recognition task to evaluate point-and-edge sensitivity. JNDs were determined using the forced-choice staircase method for the punctate deformation force of a monofilament (F;0.0044–0.010 g) and the surface roughness of stainless steel coupons (Ra; 0.177–0.465 µm) in populations of 30 and 31 individuals, respectively. Point-and-edge sensitivity was assessed by determining the letter recognition threshold (RT) based on height (h;1.5–8.0 mm) in an additional 28 individuals using a modified staircase method. While subjects had significantly lower JNDs with their tongues for both "purely-tactile" tasks (punctate: 0.0017 ± 0.0001 g vs. 0.0023 ± 0.0002 g (fingertip), $p = .018$; roughness: 0.039 ± 0.004 µm vs. 0.112 ± 0.020 µm (fingertip), $p < .001$), subjects had significantly higher RTs with their tongues for the letter identification task (3.98 ± 0.84 mm vs. 4.54 ± 1.41 mm (fingertip), $p = .0417$). The latter difference is likely attributable to the more complex nature of the RT task and the finger's frequent involvement in object recognition. Binomial statistics ($p = 1/2$, $\alpha = 0.05$) showed a significant number of subjects were better at the roughness task with their tongues ($p = .021$); however, a significant majority were better at the letter identification task with their fingers ($p = .049$); no significant difference was found for the punctate pressure task. While data appear to suggest the tongue is more sensitive to exclusively tactile stimuli, further study of other "pure-tactile" sensations should help clarify the contradictory results of the RT task.

1. Introduction

The oral cavity contains several of the most richly innervated somatosensory tissues in the body, but few studies have characterized their sensitivity, particularly when compared to other highly-innervated body sites such as the finger (for good examples, see [1–3]). The studies that have been completed often aim to equate tactile acuity with seemingly unrelated texture sensitivities [4,5], focus on elderly or diseased subsets of the population [6,7], or utilize methods specific to the oral cavity that have not been tested on other body sites [8–12]. Moreover, in the absence of a set of standardized methods for determining oral tactile acuity, the majority of the existing comparative studies utilize static or moving two-point discrimination or grating recognition tasks, both of which have shown limited reliability as tools for determining relative acuity [3,13–15].

By comparing the relative sensitivity of the poorly-characterized tongue and the more completely-characterized fingertip to a variety of tactile stimuli, insights regarding lingual innervation can be elucidated. While the high sensitivity of the fingertip is optimized to enable exploration and manipulation of the objects in the external world, the high sensitivity of the tongue provides a mechanism to do the same things with objects (foods) placed into the mouth. Given their similar roles, comparison of various oral tissues with the more highly characterized fingertip provides a better understanding of this process in the oral cavity. This knowledge can in turn serve as a platform for further studies of lingual tactile acuity and how variations in acuity may contribute to a variety of other important oral phenomena (e.g. speech, bolus formation, swallowing, texture perception, etc.). Thus, it is

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critical to establish not just a single method, but rather a suite of effective and repeatable tests which can be used to evaluate a variety of tactile cues [7].

1.1. Punctate pressure discrimination

Punctate force sensitivity has been evaluated previously in both the fingertips and oral cavity, and is thought to be a "basic" tactile cue [6,16–18]. A generally-accepted protocol for punctate pressure discrimination tasks on any biological tissue involves the presentation of Semmes-Weinstein monofilaments using the up-down forced choice protocol (see [18]). While previous studies have reported success in using the Semmes-Weinstein filaments for detection threshold identification in both the finger [6,18,19] and the tongue [4–6], others have found the filaments are insufficient for this task. Shortcomings were attributed to variance due to manufacture [20], the use of multiple filaments and/or experimenters [21], or to the fact that the lowest available force (0.008 g) was simply insufficient to establish a detection threshold [17]. The few studies that are available comparing the fingertip and tongue directly using the Semmes-Weinstein filaments have found the tongue tip to be the most sensitive body site to punctate pressure stimuli [7].

1.2. Roughness discrimination

In addition to punctate pressure sensitivity, the evaluation of fine surface roughness provides another tactile stimulus for investigation that is free from cognitive confounds. However, unlike the punctate pressure sensitivity task, there is not an established stimulus set for the evaluation of this attribute. Previous studies on the fingertip have utilized commercially available products, such as abrasive papers and fabrics [22,23], while, more recently, others have elected to utilize custom-made, polymer-based stimuli, directionally-roughened using ultraviolet ozone irradiation exposure [24]. Due to stimuli differences amongst the two proposed methods, there is variance in reported sensitivity to fine surface roughness in the fingertip. While it was generally accepted the Just Noticeable Difference (JND) thresholds in the finger for this attribute were on the order of microns, use of custom-made stimuli suggests it may be on the order of nanometers [23,24]. In the oral cavity, only a single study has evaluated roughness and did so using directionally roughed metal bars [11]. JND data from this study suggests lingual acuity is similar to that observed in the glabrous skin of the finger. Currently, no study has assessed roughness sensitivity using the same set of stimuli for both the finger and the tongue. Such an approach will allow for a direct comparison of the sensitivity of the two sites.

1.3. Point-and-edge recognition

The identification of three-dimensional letters has been utilized previously as an oral stereognosis, point-and-edge recognition task. Developed by Essick, Chen, and Kelly [13], the task uses a relatively-large, familiar sample set (e.g. a sub-set of the English alphabet), which is 3D-printed or embossed using a polymer. The use of letters is thought to provide stimuli that are still identifiable on the basis of shape, while limiting the use of non-spatial cues in discrimination, a phenomenon seen in the grating task. Although stereognosis tasks do assess tactile acuity, there is also a cognitive component associated with shape identification. Thus, while these tasks do provide insight into tactile acuity, variability may not necessarily be attributable to tactile differences alone. However, these tasks have been used in a number of studies that attempt to evaluate tactile acuity and how it relates to a variety of factors. The task has been used to assess potential connections between tactile acuity and PROP sensitivity and fungiform papillae density in females [25], food texture preferences in mothers and children [9], tongue strength [26], and age [10,26]. Importantly, this task has not been completed using the fingertips and is thus necessary before relative acuity can be established.

This current study aimed to assess the relative tactile acuity for the finger and tongue using the three aforementioned tasks. In using consistent stimuli across the two sites, a direct assessment of relative acuity could be made. Moreover, in assessing a variety of attributes, as opposed to a single attribute, a more complex understanding could be achieved. Given the high degree of sensitivity required for activities such as speech and eating, as well as the lack of an epidermis and lower deformation force required for tongue tissue, it was hypothesized that the tongue would show greater tactile acuity across all tests when compared to the finger. By comparing the tongue to the fingertips, another highly sensitive structure, we hope to 1) gain insight into the tactile sensitivity of the oral cavity, while also 2) evaluating the methods presented here for their potential use in future studies relating tactile sensitivity to the perception of food textures and preferences.

2. Materials and methods

2.1. Subjects

Subjects ($N = 87$, aged 18–30) were recruited from the greater Columbus area using The Ohio State University Sensory Database. For many tactile sensations, there is a well-established link between increased age and decreased tactile acuity [6,10,16,26–29]. Participant age was restricted to individuals 18–30 years to limit the variation in ability attributable to this factor. Additionally, while differences in tissue hardness (i.e. skin tissue vs. mucosal tissue) in the fingertip and tongue were thought to likely play a role in inherent sensitivity differences, an attempt was made to minimize these differences by excluding individuals who had visible calluses or skin thickening, as well as those individuals who participated in potential callus-forming activities, such as rock climbing, guitar playing, working in a mechanical trade, etc. [30]. Moreover, individuals with a history of xerostomia, smokers, those who were immunocompromised, and/or those who had visible sores, scars, or other surface deformations on the mouth, tongue, or fingertips were excluded. Subjects were instructed not to eat food or drink anything other than water one hour prior to their testing session. Each subject was tested individually during a single, one-hour session and paid $20 for their participation. For each study, subjects were asked to self-select which index finger they used for testing and only use that finger for the duration of the test. Subjects were recruited separately for each of the three studies, and no subject participated in more than one study. All studies were approved by the Ohio State University Institutional Review Board (2013B0277), and all data was collected under the written, informed consent of each subject.

2.2. Stimuli

Tests selected here were chosen either for their potential as evaluations of "purely tactile" sensations (roughness and punctate pressure discrimination tasks) or for their well-documented use in lingual tactile assessment (letter recognition task).

2.2.1. Punctate pressure discrimination

30 subjects' (14M/16F, ages 19–28) average JND for punctate pressure sensitivity of the fingertip and the tongue was determined using the forced-choice, up-down staircase method similar to that outlined by Linne and Simons [11]. Stimuli for this study were presented using two Luneau Cochet-Bonnet aesthesiometers (Western Ophthalmics Corporation, Lynnwood, WA). In an effort to eliminate variance due to device attributes, the current study elected to utilize a Cochet-Bonnet aesthesiometer, an adjustable force monofilament typically used in assessing corneal sensitivity, as opposed to the Semmes-Weinstein filaments used previously [31]. Beyond decreasing device number (and thus the interdevice variance), the aesthesiometers had