AEROTACTILE ACUITY AS A PREDICTOR OF SIBILANT CONTRAST

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1. INTRODUCTION

Somatosensory acuity has been shown to correlate with produced acoustic contrast distance between /s/ and /ʃ/ (Ghosh et al., 2010). This effect is independent of auditory acuity, suggesting that speech sounds have independent somatosensory and auditory perceptual goals.

The term "somatosensory", however, applies to a broad range of different sensory modalities (Hsiao & Gomez-Ramirez, 2011). It is not known whether the different somatosenses contribute independently to determining production goals. One somatosense that has been shown to play an important role in speech, but that has an unknown effect on production goals, is the aerotactile sense (Gick & Derrick, 2009).

Aerodynamic properties have long been identified as defining characteristics of sibilant sounds, viz. the feature [strident] (Jakobson & Halle 1956). Indeed, the achievement of aerodynamic goals is often seen as the purpose of the tongue shapes adopted during the production of sibilants (Iskarous et al., 2011).

The present investigation replicates Ghosh et al.'s (2010) study of contact acuity, adding to this a comparison of the aerotactile modality. We hypothesize that aerotactile acuity is an independent predictor of produced contrast distance between sibilants.

2. METHOD

21 paid volunteers, all native speakers of English, participated in this study. Data were rejected from three subjects who scored below chance or reached ceiling, and from one subject because of technical problems; the data discussed in this paper therefore came from 17 participants, 10 male and 7 female, ranging in age from 20 to 58 years.

Participants performed three tasks, designed to test for each individual a) the contact acuity of the anterior tongue, b) the contrast distance – that is, the difference in spectral energy distribution – between /s/ and /ʃ/, and c) the aerotactile acuity of the anterior tongue. The contrast distance task was performed between the two acuity tasks. The order of the acuity tasks was reversed between participants so that half performed the contact acuity task first and half performed the aerotactile acuity task first; the order of tasks did not significantly affect results.

2.1 Methods for contact acuity

This portion of the experiment was a four-way forced-choice grating-orientation judgment task similar to the one described in Ghosh et al. (2010), with the following adjustments. Participants were seated comfortably with their chin in a chin rest, their eyes closed and their tongue flat and protruded. A domed probe with grooves spaced 1.75mm apart was pressed gently against the tongue with the grooves oriented at one of four different angles, exerting a pressure of approximately 94.3g/cm² for 500ms. Probe pressure was applied by a solenoid plunger activated by a sine wave signal for each trial. Participants responded with hand gestures indicating the orientation of the grooves and their responses were logged by the experimenter. Participants were free to take breaks during this phase of the experiment. There were a total of 40 trials, with each orientation appearing 10 times. The order of the trials was randomized.

2.2 Methods for sibilant contrast distance

This portion of the experiment was a production task replicating the methods of Ghosh et al. (2010) with the following adjustments. Participants were seated comfortably in front of a computer in a sound-proof booth and read sentences from the screen. The targets, "said" and "shed", were each repeated 15 times in a random order in the carrier phrase "He ___ a lot." These productions were recorded using the internal microphone of a Macintosh OS X computer at a sampling rate of 44100 Hz. The middle portion of each target word's sibilant was isolated in Praat. The centre of gravity, skewness and kurtosis of each sibilant production were calculated using Praat and the average value of each spectral moment was calculated for each sibilant. These values were used to calculate the average contrast distance (CD) as the Euclidean distance between /s/ and /ʃ/ in the three dimensional space defined by the three acoustic measures.

2.3 Methods for aerotactile acuity

This portion of the experiment was a two-way forced-choice task. Participants were seated comfortably in a sound-proof booth with their eyes closed and tongue flat and protruded. A piece of tubing connected to an air compressor was placed 5cm from the tongue surface. Participants sat with their back and head against a board to control distance from the tubing and listened to white noise over sound-isolating headphones to mask the sound of the air puffs. Puffs of air approximately 330ms long were delivered onto the tongue at two different strengths, a light puff of approximately 0.27 Pa and a strong puff of approximately 0.53 Pa, in random order. Participants were asked to correctly identify the strength of the puff and logged their responses on a keyboard. There were 80 trials in total, such that each puff strength appeared 40 times. The first 40 trials were treated as a practice section and were not analyzed further, leaving 40 experimental trials.

2.4 Statistical analyses

The contact acuity d-prime score (CA) and aerotactile acuity d-prime score (AA) were calculated for each subject in R (R Development Core Team, 2011) using the package psyphy (Knoblauch, 2012). Linear modeling and Pearson's product-moment correlation tests were performed using R (R Development Core Team, 2011).

3. RESULTS

Pearson's product-moment correlation between CD and AA was significant ($r=0.73$, $p<0.001$). In contrast, there was no significant correlation between the CD and CA ($r=-0.16$, $p=0.5516$), nor between the two acuity measures ($r=0.02$, $p=0.9428$).

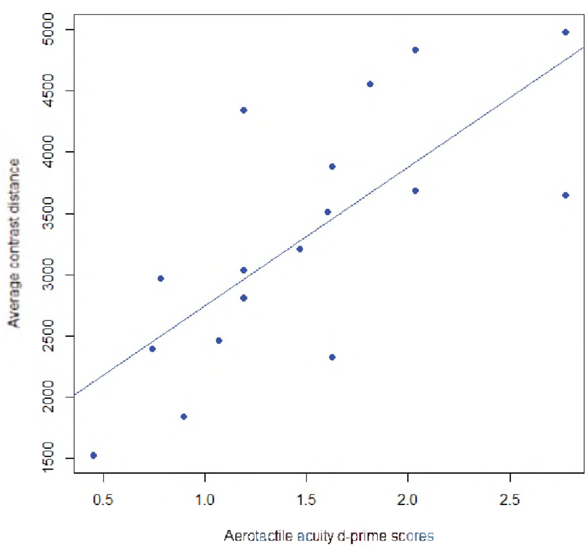

Figure. 1. Contrast distance vs. aerotactile acuity

Multiple linear regression shows that AA was a significant predictor of CD ($\beta=2015.4$, $t=3.009$, $p=0.0101$) while CA ($\beta=826.6$, $t=-1.421$, $p=0.1788$) and the interaction between the two acuities were not ($\beta=-914.2$, $t=-1.421$, $p=0.1788$). Simple linear regression of the relationship between AA and CD shows that aerotactile acuity was a significant predictor of contrast distance ($\beta=1134.6.4$, $t=4.181$, $p<0.001$, adjusted $r^2=0.51$), while linear regression of the relationship between CA and CD shows that contact acuity was not ($\beta=-248.2$, $t=-0.609$, $p=0.5516$, adjusted $r^2=0.51$).

We initially set out to replicate Ghosh et al's (2010) results for the contact modality. In the overall analysis, contact acuity results were not significant. Following Ghosh et al. (2010), we performed a median split based on participants' acuity scores and repeated the correlation tests. There was a small, though not statistically significant, tendency toward a positive correlation between CA and CD in the low acuity group ($r=0.53$, $p=0.1461$). With more data or a more rigorous replication of Ghosh et al. (2010)'s contact acuity protocol, this tendency would likely be significant.

4. DISCUSSION

Our results indicate that speakers' aerotactile acuity is an independent predictor of their produced contrast distance. This is perhaps unsurprising given the high volume of airflow that passes over the anterior portion of the tongue during the production of sibilants. Nevertheless it indicates that aerotactile feedback is important for producing sibilant contrasts.

The fact that multiple sensory factors play independent roles in speech allows for the possibility that any modality could reasonably play an independent role. For example, the work by Ménard et al. (2009) on the speech of blind and sighted individuals indicates that the visual modality is also an independently important factor in speech production. Thus, speech production can perhaps be best understood as an interplay between many independent modalities.

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