A Comparison of Vowel Acoustics Between Older and Younger Adults

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ABSTRACT

Previous research has shown a difference in vowel acoustics between older and younger adults, possibly related to age-related changes in vocal tract morphology. Data suggest that vowel acoustics may vary as a function of neighborhood density and word frequency in older adults, possibly due to the mediating influence of lexical access. However, no studies have examined the relationship of density and frequency to vowel dispersion in older adults. This investigation examined whether these two factors interact. Results show that older adults had overall lower-frequency formants, and qualitatively different-shaped vowel spaces, than the younger adults, but the influences of word frequency and neighborhood density on the acoustic characteristics of vowels were statistically equivalent in both groups.

Keywords: Neighborhood Density, Word Frequency, Vowel Acoustics, Age Differences

1. INTRODUCTION

This investigation compares age-related differences of vowel production in a group of healthy older adults and sex-matched younger adults. A number of studies have documented that the acoustic characteristics of vowels change globally during normal aging [1,2,3,]. Both [1] and [3] observed that older talkers had lower average F1 values than younger adults. It was found that overall vocal-tract volume, but not length, increased with age [3].

These data have provided important information regarding the origin of some of the characteristics of the older talkers. However, it is clear that not all age-related differences can be reduced to changes in vocal-tract morphology across the lifespan. A comparison of two large-scale normative studies of vowel acoustics, carried out in the early 1950s [4] and the mid-1990s [5] suggests that the production of low front vowels and high back vowels has changed in that approximately 45-year span. Low-front vowels are now being produced with lower tongue/jaw positions and back vowels are produced with greater anterior tongue position. It is unknown, however, if older adults have maintained the “older” more conservative forms or have their productions changed to reflect contemporary pronunciation. If older adults have maintained the more conservative pronunciation variants, then we should see qualitative differences in age-related vowel differences in different vowel types. There is, however, one anecdotal reference to suggest that vowel production may shift with age to reflect more contemporary forms. Acoustic analysis of radio broadcasts of Queen Elisabeth II from the 1950s through the 1980s found that her pronunciation gradually shifted to a more contemporary pronunciation style [6]. To our knowledge, there has been no systematic examination whether older adults’ productions reflect this shift.

In this paper, we also consider whether age-related vowel acoustic differences might be attributable to a second source of variance. A parallel line of research has examined the acoustic characteristics of vowels as they relate to words' frequency of occurrence and phonological neighborhood density [7,8,9]. These works have shown that vowels in words with high frequencies (HF) of occurrence and low phonological neighborhood densities (LD) are produced closer to the center of the F1-by-F2 vowel space than those in low-frequency (LF) and high-density (HD) words when produced by young adults [7,8,9]. There are a number of conjectures about why this is so. This may reflect speakers' hyperarticulation of LF and HD words, with the tacit understanding that these types of words are harder to recognize than HF and LD words. In contrast, it may reflect the influence of these variables, particularly word frequency, on lexical access.

It is not known, however, whether this effect is also observed in older adults. Some research has found older adults have greater difficulty identifying words from phonetically similar neighborhoods as compared to young adults [10]. Others have shown that neighborhood density and word frequency affected tip-of-the-tongue (TOT) productions differently in older adults as compared to younger adults [11]. If lexical retrieval, comprehension and TOT tasks are affected by age then an older adult's speech production may also be affected.

2. METHODS

2.1 Participants

Ten older and 10 younger adults participated in this study with five men and five women in each group. All were mono-lingual speakers of American English with no history of speech, language or hearing disorders. All participants gave informed consent after prior approval from our Institutional Review Board. The older group's average age was 76 years, SD = 2;3 and the younger groups average age was 23;4, SD=3. The data for the younger adults were taken from a quasi-random subset who participated in Experiment 2 in [8].

2.2 Stimuli

The stimuli were a subset of 32 of the 80 words from [8]. The stimuli consisted of CVC words with monophthongal vowels (/i/, /ɑ/, /eɪ/, /ɛ/, /æ/, /oʊ/, and /u/). High- and low-frequency and density lists were constructed by conducting a median split for the raw frequency and frequency-weighted neighborhood density values for the CVC words in the Hoosier Mental Lexicon [12] that were likely to be familiar to most listeners, based on their having a mean familiarity score of 6.5 or greater on a 7-point scale.

The HD words had an average frequency-weighted neighborhood density of 188.4; the LD words 32.6. This difference was significant, $F(1,28)=49.5$, $p<0.001$, partial $\eta^2=0.64$. The differences in neighborhood density for HF and LF words were statistically equivalent, as were the differences in frequency for the HD and LD words.

The HF words had an average frequency of 182.3 instances per million in the corpus described in [13]; the LF words had an average of 6.8 instances per million. This difference was significant, $F(1,28)=11.4$, $p=0.002$, partial $\eta^2=0.29$.

2.3. Analysis

Analysis was performed using Praat vs 4.3 software [14].

Vowel segments and their durations were determined from both the waveform and broad-band spectrogram displays with linear predictive coding (LPC) superimposed over the spectrogram display. Vocalic portions were hand-segmented using a consistent set of criteria.

From the marked segments, vowel duration and Bark-scaled F1 and F2 [15] were extracted automatically and hand-corrected when determined to be outliers. For each stimulus type, mean vowel duration, mean F1, mean F2, F2 range, F1 range, and mean vowel-space dispersion were calculated. The mean F1 and F2 values collapsed for all vowels provided an average centroid value within the vowel space. The range for F1 was calculated by taking the difference of the average first formant values for /i/ and /ɑ/. The range for F2 was calculated by taking the difference of the average second formant values for /i/ and /oʊ/. The ranges of F1 and F2 provided a description of the shape of the vowel space – F1 being equivalent to height and F2 to width.

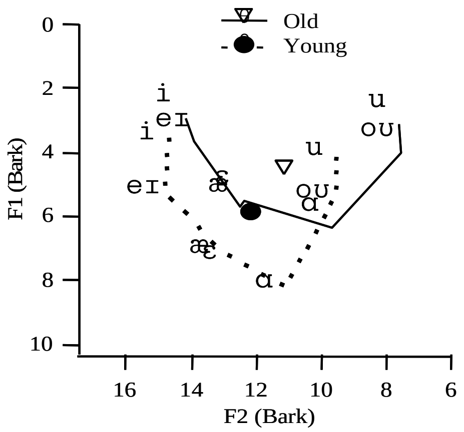
The calculation of vowel space was done according to the method of [15] and was determined by taking the average euclidian distance of the individual vowels from the center of the vowel space.

3. RESULTS

3.1 Vowel-Space Shape and F1/F2 Centroids

The first set of analyses examined whether average vowel production differed between the older and younger adults. The first analysis examined spacing of the entire ensemble of vowels in the F1 by F2 vowel space. Figure 1 displays average vowel space and average centroid values of the vowel spaces for the two groups averaged across all stimulus types. F1 and F2 values are lower for the older group. Separate, one-factor multivariate analyses of variance (MANOVA) were used to examine the influence of age-group on F1 and F2 values for the seven vowels. For F1, the main effect of age was significant ($F[7,12]=8.25$, $p = 0.001$, partial $\eta^2 = 0.83$, Wilks' $\lambda = 0.172$). Age influenced the F1 of all seven vowels studied ($F[1,18] = 16.59 - 44.54$, all ps < 0.001). The main effect of age was also significant for F2, (F[7,12]=3.69, p = 0.023, partial η^2 = 0.68, Wilks' λ = 0.317). Analysis showed that age influenced formant values for F2 at the $\alpha < 0.05$ level only for the back vowels /u/, /oʊ /, and /ɑ / (F[1,18] = 10.97-15.95 ps = 0.001-0.004).

Figure 1: Vowel space, expressed in F1/F2 bark values, for the young adults (dashed line) and for the old adults (solid line). The centroid value for the young adults is represented by the solid circle and the unfilled inverted triangle for the older adults.

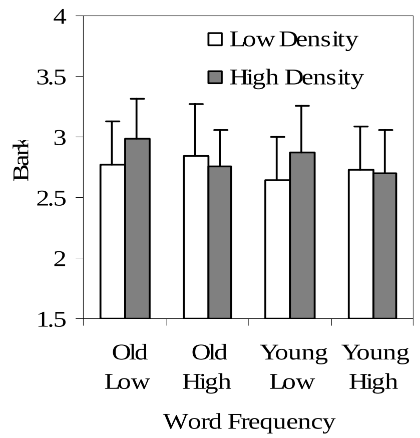


The second analysis examined whether there were quantitative differences in the shape of the F1 by F2 vowel space. This analysis showed that older adults retained the historically less-advanced more-back pronunciations of back-round vowels, as well as the less-extreme productions of /ɑ/ and /æ/, than the younger adults. Two separate univariate ANOVAs showed that the older adults produced vowel spaces that were significantly 'shorter' in height (F1 dimension) than those of the younger adults F[1,18]=12.76, p = 0.002, partial η^2 = 0.42) and significantly 'wider' than those of younger adults F[1,18]=4.58, p = 0.046, partial η^2 = 0.203.

3.2 Vowel-Space Expansion in Relation to Density and Frequency

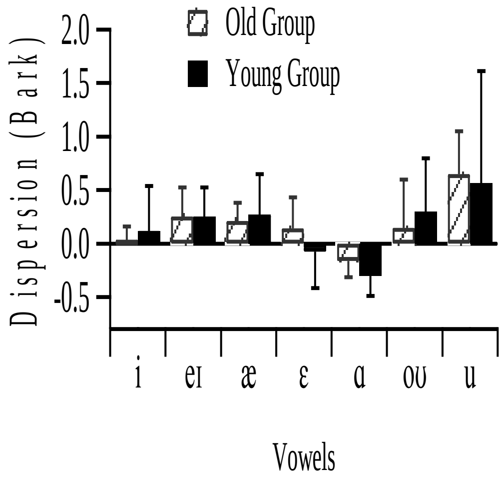
Means and standard deviations of F1/F2 dispersion are shown in Figure 2. A mixed-design ANOVA was performed with age as the between-subjects factor and word frequency and neighborhood density as the within-subject factors. No significant main effect for age and no significant interactions with age were found. Significant main effects were found for frequency, F(1,18) = 4.67, p = 0.044; and for density, F(1,18) = 4.65, p = 0.045. A significant interaction was found for frequency and density, F(1,18) = 20.87, p < 0.001, partial η^2 = 0.537. Follow-up t-tests with a Bonferroni-corrected α level of 0.025 showed that LF and HD words had significantly greater dispersion than HF and HD words, t(19) = 5.975, p < 0.001; and that LF and HD words had significantly larger dispersion than LF and LD words, t(19) = 4.771, p< 0.001.

Figure 2: Means and standard deviations for F1/F2 expansion in the high- and low frequency words and the high- and low-density words for the young adult and the old adult groups



Because vowel height and width were different between the older and younger group, a set of informal analyses examined if different vowels contributed to the difference in dispersion between vowels in HD and LD words. Only vowels in LF words were examined, as this was the only category in which density affected vowel-space dispersion. Figure 3 shows the difference of dispersion between HD and LD of LF words for each vowel studied for the old and young groups. In this figure, 'dispersion' refers to the mean Euclidian distance of each of the vowels from the arithmetic center of the F1/F2 space. As this figure shows, four of the vowels (/eɪ /, /æ /, /oʊ /, and /u/) showed dispersion differences in the expected direction, while one vowel, /ɑ /, showed consistent differences in the opposite-than-predicted direction. Because of the high between subject variance, a series of nonparametric sign tests were used to examine whether older and younger adults differed in the influence of density on different vowels. Consistent with the results of the group ANOVA on vowel-space dispersion, no influence of group was found for any category (All z's < 1.5, all p's > 0.15).

Figure 3: Means and standard deviations for the difference of dispersion between high and low neighborhood density of low frequency words, separated by vowel and by age-group. Positive values demonstrate greater dispersion in high density words and negative values show greater dispersion with low density words.



4. DISCUSSION

Our analyses found support for age-group differences between the older and younger adults. First, the older adults demonstrated lower formant values consistent with earlier findings [1,3]. Second, as a group the older adults produced wider and shorter vowel spaces, likely reflecting their use of the more-back pronunciations of /u/, /oʊ/ and /ɑ/, reflecting the more conservative pronunciation differences described by [5]. Could reduced strength in the older group account for some difference in vowel shape? This is most likely not the case, because speech production is typically produced at the lower level of physiologic support [16]. Thus even if there was a reduction of strength in the older group, it would most likely have no impact on vowel production. However, in light of the shift of formant values and a difference of pronunciation styles between the older and young adult groups, the effect of neighborhood density and word frequency on vowel dispersion was statistically equivalent for both groups. Moreover, the finding that the effect was equivalent sized for both groups suggests that the disproportionate influence of phonological neighborhood density on lexical access in older adults does not extend to acoustic detail in vowels.

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