Sensorimotor maps and vowel development in English, Greek, and Korean: A cross-linguistic perceptual categorization study

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Developing Vocal Tracts:

Modeling Production, Testing Perception

•As children age, their vocal tracts grow. This growth is nonlinear, and results in disproportionate growth of the pharynx (Vorperian et al., 1997) This growth forces children to modify the articulatory settings used to produce different vowels.
•Acoustic simulations of the maximum vowel spaces of children at different stages (Boë and Maeda, 1997) of development are shown in Figure 1. This type of output has been used to synthesize a range of vocal productions for different vocal-tract growth stages.
•Perception studies have examined the labels that adults attribute to productions of hypothetical vocal tracts at different stages of development (e.g., Ménard et al., 2004, 2009; McGowan, 2006). Studies by Ménard and colleagues have shown that even the youngest vocal tracts are capable of generating tokens that are identified as the point vowels /i/, /æ/, /ɑ/, and /u/. As vocal tracts grow, more back and high vowels are identified.
•These studies were conducted with English and French listeners. The purpose of this study was to extent this finding to two more-symmetric vowel systems, those of Korean and Greek, shown in Figures 2 through 4. This experiment is part of a larger collaborative project on the dynamics of production-perception relationships during speech-sound acquisition across languages.

The research questions this investigation addresses are:

- Do the vowels that are shared across the languages occupy the same part of the perceptual vowel space? If not, does language specificity in the perception of shared vowels interact with vocal-tract growth stage?
- Do Greek and Korean listeners perceive point vowels for all vocal-tract growth stages?
- Do Greek and Korean listeners show the same effect of vocal-tract growth stage on the perception of vowel height and vowel backness as listeners do?

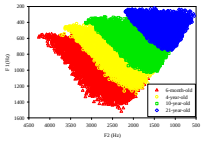

Figure 1. Maximal vowel spaces for vocal tracts at four growth stages

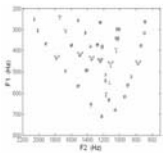

Figure 5. Thirty-Eight Commonly Occurring Vowels

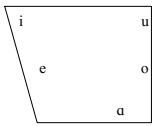

Figure 2. Greek Vowels

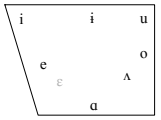

Figure 3. Korean Monophthongs

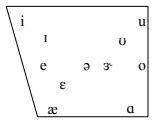

Figure 4. English Monophthongs

Acknowledgments

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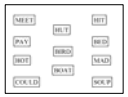
Methods

•Stimuli were 408 synthesized vowels. These represented 38 tokens each generated with articulatory-acoustic models of vocal tracts at seven growth stages: 6 months, 2 years, 4 years, 5 years, 10 years, 16 years, and 21 years. The 38 tokens were meant to represent 38 commonly occurring acoustic prototypes, as determined by previous cross-linguistic surveys (See Figure 5). Each of these was fit to an appropriate location in the maximal vowel space for each vocal-tract stage. The f0 of the stimuli was determined by a previous study of the relationship between f0 and vowel perception across different vocal-tract growth stages.
•21 Greek-speaking Listeners, 20 Korean-speaking Listeners, and 21 English-speaking Listeners were tested in their home country (Thessalonica, Seoul, or Columbus, OH) by a same-language-speaking research assistant, with all instructions translated to the native language.
•Stimuli were blocked by vocal-tract age. Presentation was randomized within blocks. Block order was randomized.
•Listeners heard a vowel, then clicked on a screen to indicate their response. Response screens are shown below

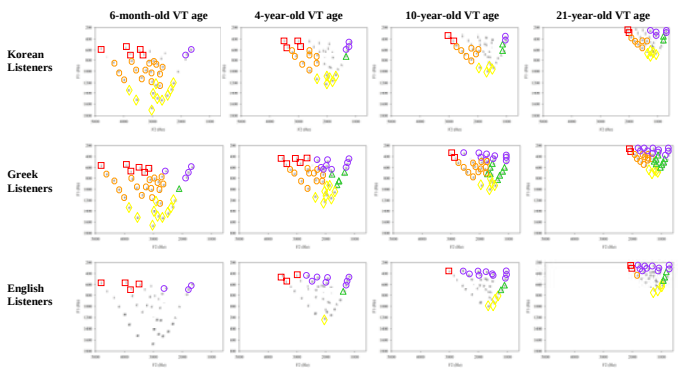


Figures 6-8. Response scree for Korean (left), Greek (middle), and English (right)

Results 1

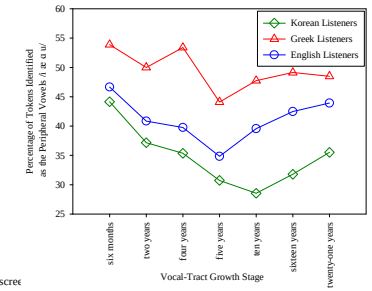
Predominantly Perceived Vowels

•The predominantly perceived vowel for each stimulus was calculated by
  •(a) determining first whether any one vowel was identified at greater than chance levels, using the binomial probability formula. The number of responses needed to qualify a label as occurring at greater-than-chance levels differed across languages because of the different number of possible responses.
  •(b) For stimuli that were identified at greater than-chance levels, the label that received the most proportion of responses was chosen as the predominantly perceived vowel.
  •(c) Vowels that were not identified at greater-than-chance levels, or which had a tie between two labels were classified as having no predominant percept.
•Vowel charts for four vocal-tract ages (six months, four years, ten years, and twenty-one years) are shown. Vowels common to the three languages are highlighted. **The perception of vowels shared across the three languages was more-similar for older VT models than younger ones.**



Results 2

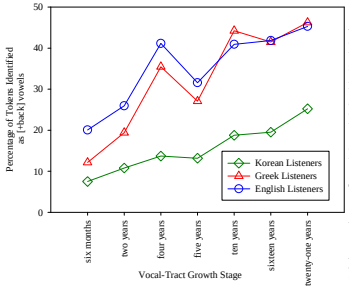
Perception of Point Vowels



•The proportion of vowels identified as /i æ ɑ u/ was calculated separately for individual listeners for the seven vocal-tract growth stages. There were submitted to a two-factor mixed-model ANOVA with VT growth stage as the within-subjects model and listener language as the between-subjects factor
•There was a significant effect of listener language, F[2,59] = 37.4, p<0.001 and of VT growth stage, F[2,354] = 22.7, p < 0.001. These interacted significantly, F[12,354] = 3.0, p=0.001. The interaction is shown in the Figure to the left
•**Point vowels were perceived in all VT growth stages in all three languages.**

Results 3

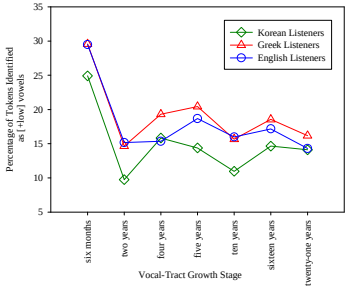
Perception of Backness



•The proportion of back vowels ({/u/, /o/, /ʊ/} was calculated separately for individual listeners for the seven vocal-tract growth stages. There were submitted to a two-factor mixed-model ANOVA with VT growth stage as the within-subjects model and listener language as the between-subjects factor
•There was a significant effect of listener language, F[2,59] = 51.7, p<0.001 and of VT growth stage, F[6,354] = 163.1, p < 0.001. These interacted significantly, F[12,354] = 10.6, p < 0.001. The interaction is shown in the Figure to the left.
•**Korean-speaking listeners perceived proportionately fewer back vowels than did Greek- and English-speaking listeners.**

Results 4

Perception of Height



•The proportion of low vowels ({/æ/, /ɑ/} was calculated separately for individual listeners for the seven vocal-tract growth stages. There were submitted to a two-factor mixed-model ANOVA with VT growth stage as the within-subjects model and listener language as the between-subjects factor
•There was a significant effect of listener language, F[2,59] = 5.1, p = 0.008 and of VT growth stage, F[6,354] = 79.4, p < 0.001. These interacted marginally significantly, F[12,354] = 1.7, p = 0.056. The interaction is shown in the Figure to the left.
•**Korean-speaking listeners perceived fewer low vowels than did English- and Greek-speaking ones**