Development of temporal and spectral characteristics in the speech of hearing impaired preschoolers

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Main Point

The development of temporal and spectral speech properties of hearing impaired (HI) children is not fully understood, particularly in children with early- versus late-identified hearing impairment. Results from this longitudinal study (a) document development of vowel production and (b) indicate a speech production advantage for children with early-identified hearing loss. We offer a few possible directions to improve understanding and linguistic outcomes in 4- and 5-year olds with hearing impairment.

Background

Vowels are central to speech production and speech intelligibility (Peterson & Barney 1952, Fant 1960, Hillenbrand et al 1995, Neel 2008).

Sensitivity to the durational and spectral features of vowels has been shown in newborns (Eimas et al 1971, Aldridge et al 2001), and continues to develop until puberty or later (Lee et al 1999).

Development of vowel production in children is generally toward shorter durations and less extreme formant values (Lee et al 1999, Vorperian & Kent 2007).

Hearing impaired children's linguistic development is influenced by:

a) audibility (Stelmachowicz et al 2004; Donahue 2007)

b) age at which hearing loss (HL) is identified (Moeller 2007)

c) intervention strategy (Uchanski & Geers 2003)

Developmental studies comparing children with normal (NH) and impaired hearing (HI) show:

a) vowel durations in hearing impaired talkers are longer (Monsen 1974, McGarr & Harris 1983, Osberger 1987, Uchanski & Geers 2003).

b) vowel formants in hearing impaired talkers are more extreme (McGarr & Harris 1983, Uchanski & Geers 2003, Pratt & Tye-Murray 2008).

Public Policy

About 3 per 1000 children born in the US have hearing loss. Early detection procedures are inexpensive (~$50/child), non-invasive, and effectively reliable. Myriad benefits are reported in the literature (Apuzzo & Yoshinago-Itano 1995, Donahue 2007, Moeller 2007, Durieux-Smith et al 2008).

In July 2008, the U.S. Department of Health and Human Services, Preventive Services Task Force released a B-grade recommendation concerning newborn hearing screening concluding "that the net benefit of screening all newborn infants for hearing loss is moderate" (USPSTF 2008).

Early access to auditory experience may play an important role in language development for infants with hearing loss; empirical study of the benefits will continue to guide public policy.

Research Questions

1. Do HI children develop vowel space and duration in a manner similar with NH children?

2. Do children with early- versus late-identified hearing impairment differ in the development of their vowel productions?

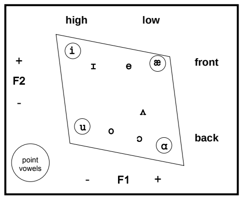
Methods

Materials

point vowels are underlined and bold

bat	house	**pot**	sick	bay
hoop	six	**zoo**	**beat**	**key**
spot	buy	**bat**	kid	stick
bye	kids	**see**	**tap**	**cap**
pat	**tea**	tie	**do**	pie
rip	way	**hop**	write	tight
light	lip	right	**mean**	lay
moon	my	why	**new**	might
		white		

CSIT word list (Kent et al 1994)



$$\text{Vowel Area (kHz}^2) = 0.5 \times [\ (/i/F2 \times /æ/F1 + /æ/F2 \times /ɑ/F1 + /ɑ/F2 \times /u/F1 + /u/F2 \times /i/F1\ ) - (\ /i/F1 \times /æ/F2 + /æ/F1 \times /ɑ/F2 + /ɑ/F1 \times /u/F2 + /u/F1 \times /i/F2\ )\ ]$$

Vorperian, H. K., & Kent, R.D. (2007)

Task

Listen-and-repeat game of isolated, monosyllabic CSIT target words (Kent et al 1994). Experimenter fed a plastic chip to a purportedly hungry puppet after each repetition.

Total corpus

31 target words (× 1-2 repetitions)

× 2 ages (48- and 60-months)

× 19 talkers

~2000 total target vowels

Talkers

12 normal hearing children

3 late-ID hearing impaired children

4 early-ID hearing impaired children

All children were involved in a broader longitudinal study of language development conducted at Boys Town National Research Hospital

⟶ 3 of 4 early ID children are cochlear implant (CI) users who received implant at mean age of 20.3 months and used hearing aids before implantation.

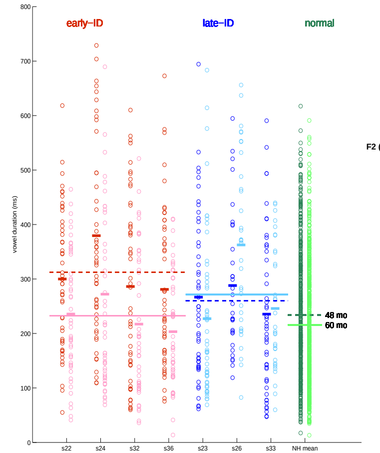
⟶ Children with hearing aids were fitted binaurally with optimal audibility.

HEARING STATUS

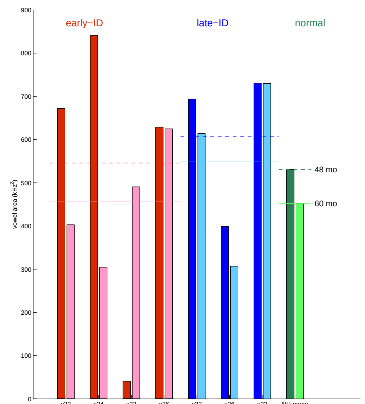
	early-ID	late-ID	normal
number of children	4	3	12
age ID (mos)	2.5	30.3	n/a
age aided (mos)	4.7	31.5	n/a
PTA (dBHL, left | right)	91.3 | 83.8	34.8 | 43.5	n/a

Measurements:

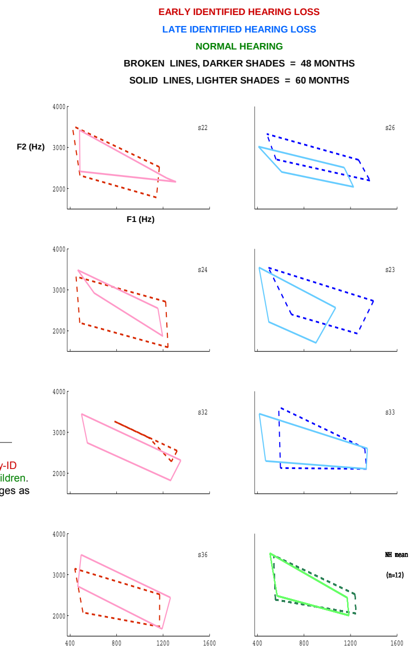
Segment boundaries were marked using Praat (Boersma & Weenink 2008). Durations and formant values were collected using an automated script customized for children.



KEY RESULT of vowel duration study: Developmental trajectory of early-ID hearing impaired children's vowel durations is similar to normal hearing children. Late-ID hearing impaired children do not show the same age-related changes as normal hearing children in either trajectory or absolute levels.



KEY RESULT of vowel area study: Development of early-ID hearing impaired children's vowel production area is similar to normal hearing children's development. Late-ID hearing impaired children show a similar degree of relative change, but do not acheive the same absolute levels.



Vowel area in F1 × F2 space for individual hearing impaired subjects and pooled normal hearing subjects at 48 and 60 months.

Statistics:

Lilliefors tests indicate data are not uniformly normally distributed, so non-parametric tests are reported. Two-sided, Wilcoxon signed-rank test statistics were used on duration data; a paired, two-sided sign-test was used for vowel space area statistics. For both, lower *P* values indicate greater probablility of within-subject production differences from 4 to 5 years old.

Vowel duration differences by age

Group	$P_{dur}(4yr \neq \hat{\mu}5yr)$	$P_{dur}(5yr \neq \hat{\mu}4yr)$
s22	< 0.003	< 0.001
s24	< 0.002	< 0.001
s32	< 0.003	< 0.001
s36	< 0.010	< 0.002
HE, pooled	< 0.001	< 0.001
s23	0.177	< 0.020
s26	< 0.006	< 0.025
s33	0.363	0.695
HL, pooled	0.157	0.988
HI, pooled	< 0.001	< 0.001
NH, pooled	< 0.047	< 0.001

Vowel space area difference by age

Group	$P_{area}(4yr \neq 5yr)$
all Subjects	< 0.020

Note: early- and late-identfiied hearing loss subject groups are only 4- and 3-member groups, respectively. Because of this small *n*, statistics by subgroup are not performed.

Conclusions

1. Vowel duration and articulation space are independently controlled in speech production. Early-identified children performed more like normal hearing children than did their later-identified peers on both measures.

2. Shorter vowel durations and smaller vowel production areas in early-identified HI children and NH children are consistent with previous reports. With respect to vowel area, three of four subjects were cochlear implant users (s22 was a hearing aid user), and it is possible that cochlear implant use correlates with improved production space characteristics (i.e., a smaller vowel area). This possibility is supported by the single-subject report of a CI user by Ertmer (2001). Early-ID and cochlear implantation are interacting factors determining auditory experience, though the nature and degree of this interaction is as yet unclear.

3. Early-identified/CI children performed more like normal hearing children than their later-identified peers, despite having greater degrees of hearing loss (early-ID children had profound hearing loss, late-ID children had mild-to-moderate hearing loss). Early-identified/CI children were also provided with earlier intervention—three of four received cochlear implants—which could help explain this effect.

4. Extended vowel duration in certain populations could impact aspects of speech production (e.g., coarticulation and intelligibility). A better understanding of outcomes could lead to improved clinical intervention in late-identified hearing impaired populations, especially with vowels (not typically a focus in clinical speech-language pathology). Future work could profitably contribute to this understudied area.

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