PRENASALIZATION IN GREEK-LEARNING CHILDREN WITH COCHLEAR IMPLANTS AND TYPICAL HEARING

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ABSTRACT

This work compares nasalance measures for word-initial consonants in Greek-learning children with typical hearing and with cochlear implants [CIs]. An interesting feature of Greek is that many dialects employ prenasalization of phonemically voiced stops. One can anticipate that the rapid shift between an open vs. closed velopharyngeal port represents a challenge to typical children, and all the more so for those who do not have typical hearing. Greek-speaking children with CIs have been found to have longer prevoicing, which could reflect greater nasal coupling. Current results show that children with CIs, compared to those with NH, have a lower proportion of prevoicing; higher nasalance values for the consonant, vowel, and word; and greater variability in nasalance measures for the consonant, vowel, and word. Some children with CIs showed considerable carryover nasalization from the initial stop consonant. Despite these group-level patterns, speaker-specific variation is extensive in both groups.

Keywords: Greek, prenasalized stops, children, cochlear implantation

1. INTRODUCTION

1.1 Effects of deafness and cochlear implantation on speech production

Past work shows that hearing loss can lead to atypical patterns of nasality in speech, which could be either hyponasality or hypernasality [1–3]. Some studies suggest that cochlear implantation can improve oro-nasal balance in children [4], but others find that increased or decreased nasality compared to normally-hearing [NH] peers may persist [5–7]. To date, instrumental studies of nasality post-cochlear implantation have not sampled widely across languages. Conceivably, some of the discrepancies that exist in the literature could reflect cross-linguistic differences.

1.2. Prenasalization in Greek

Many speakers of Modern Greek produce voiced stops with prenasalization [8–9], i.e. nasal energy is high early in the consonantal closure and diminishes over time. The magnitude of prenasalization may be higher in children than adults [10–11], and could facilitate phonation in a small vocal tract. Interestingly, a recent study [12] found that Greek-learning children with CIs produced longer prevoicing durations than typical-hearing counterparts, which would be consistent with greater nasal coupling in the CI group.

Both prevoicing and nasality are low in amplitude and involve "hidden" articulators. These factors, combined with the rapid velar elevation required to go from a nasal sound to an oral sound, could make this phonetic pattern particularly difficult for those with prelingual deafness. The current work thus assessed patterns of prenasalization in typically-developing children and those with cochlear implants [CIs] who are learning Greek as their first language. The data can also provide insight into the nature of inter-articulatory timing in children with CIs.

2. METHODOLOGY

2.1. Speaker information

Data are shown for 16 speakers: Eight with cochlear implants and eight age-matches with typical hearing (Table 1). Most children with CIs were implanted between 16 and 38 months, except for speaker CIF4_17 who received her implant at 14;10 years.

2.2. Speech stimuli

Target words contained initial /b, d/ in disyllables (see Table 2). Children produced the words in randomized order in response to a visual stimulus and, particulalarly for the younger children, often an oral prompt. Five productions were elicited. Note that the word /dinɑ/ allows assessment of carryover as well as anticipatory nasal coarticulation.

SpeakerID	Age	SpeakerID	Age
CIM7_4	4;2	NHM11_4	4;4
CIM3_4	4;7	NHF12_4	4;6
CIF3_5	5;3	NHM7_4	4;11
CIF1_5	5;10	NHF11_6	6;0
CIM5_6	6;6	NHM8_6	6;6
CIM6_7	7;4	NHF13_7	7;0
CIF5_8	7;10	NHM6_8	8;4
CIF4_17	17;3	NHF10_16	16;10

Table 1: Speakers and ages (years;months). Children with CIs are at left and those with NH are at right. Gender is indicated as M or F.

Orthog.	IPA	Gloss
μπύρα	'biɾa	*beer*
μπαλιά	ba'lja	*a soccer pass*
Ντίνα	'dina	*A name*
ντεφι	'dɛfi	*tambourine*

Table 2: Stimulus items

2.3. Instrumentation and analysis

2.3.1. Hardware

Data were collected via the Kay Elemetrics™ (now Pentax) nasometer system. The device employs a stabilizing headset, a stiff plastic plate that rests at the upper lip, and microphones above and below the plate to capture nasal and oral energy, respectively. The system software outputs a nasometer value that represents the ratio of nasal to oral energy. Higher nasalance scores represent a stronger nasal signal.

2.3.2. Labeling

The oral and nasal microphone data were opened in Praat [13] and labeled for the word duration, the duration of any prenasalization, and the duration of the first-syllable vowel (see Figure 1). Note that *any* periodic acoustic energy observed prior to the stop release was labeled on the 'prenasalization' tier (cf. Figure 1) even if that region appeared to contain closure voicing rather than nasalization. That is, rather than making a subjective decision as to what amounted to prenasalization, we simply obtained nasalance values over all such labeled regions. These cases were infrequent in the dataset.

The acoustic data are low-passed filtered as part of the nasometer processing; this is evident in the spectrogram. Segmental labeling therefore relied on low-frequency information and amplitude changes.

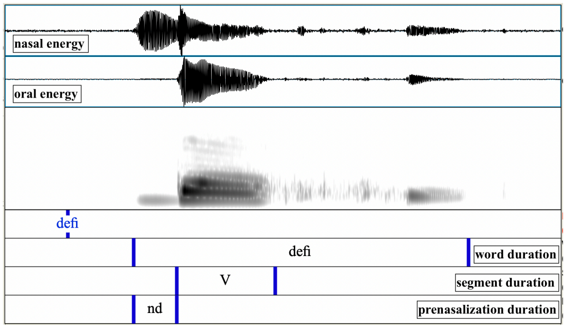

Figure 1: Labeled data in Praat. The two waveforms represent the nasal and oral microphone signals. The spectrogram scale is 0–4000 Hz. The duration shown here is about 1.4 s. This example is from NHF12_4 (four years of age).

2.3.3. Subsequent processing

The Praat time labels were loaded into Matlab, along with the nasometer output signals (oral energy, nasal energy, and nasalance ratio, all taken at 8 ms intervals). Word, prenasalization, and segmental (here, vowel) durations were extracted from the long nasometer files. From these extracted portions, we obtained nasalance averages and standard deviations for each word, prenasalized region, and vowel. Note that these standard deviations (SDs) reflect variation in nasality within individual productions, so, e.g., if a child maintained a rather consistent velar position during a vowel, the SD for that production would be low.

3. RESULTS

3.1. Group-level data

3.1.1. Prevalence of prevoicing

Percentages of labeled prevoiced/prenasalized regions (cf. section 2.3.2) were 76.3% in the CI group and 89.4% in the NH group. This difference was significant (Pearson's χ^2=8.655, df=1, p=0.003). The frequency of prevoicing/prenasalization shows no apparent relationship with age (see Figure 2).

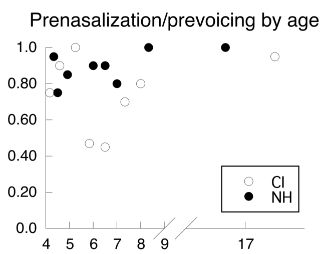

Figure 2: Proportion of tokens with prenasalization/ prevoicing as a function of age for the two groups. The x-axis was split in light of the large age gap between the two oldest speakers and the rest of the participants.

WdAvg	n	mean	sd	median	se
CI	154	27.97	18.11	25.62	1.46
NH	160	18.43	13.68	13.56	1.08
PreNasAvg	n	mean	sd	median	se
CI	119	38.11	28.51	38.96	2.61
NH	143	16.29	20.58	4.00	1.72
VAvg	n	mean	sd	median	se
CI	128	21.64	15.72	17.57	1.39
NH	150	14.75	10.65	10.97	0.87
PreNasDur	n	mean	sd	median	se
CI	119	0.15	0.08	0.14	0.01
NH	143	0.12	0.06	0.11	0.01

Table 3: Group-level nasalance data (counts (N), means, standard deviations, medians, and standard errors) shown for whole words, the prenasalized region, and the vowel. Nasalance is a percentage; durations are in seconds. The differences in numbers of tokens reflect cases where finer segmentation could not be made with confidence. For example, if a child produced a medial glide instead of a medial flap, we could obtain word duration but not a reliable measure of vowel duration.

WdSD	n	mean	sd	median	se
CI	154	21.29	11.7	24.94	0.94
NH	160	18.43	13.68	13.56	1.08
PreNasSD	n	mean	sd	median	se
CI	119	28.73	16.65	35.22	1.53
NH	143	15.91	16.29	10.91	1.36
VSD	n	mean	sd	median	sec
CI	128	9.86	7.68	8.1	0.68
NH	150	8	7.77	4.96	0.63

Table 4: Group-level standard deviations for whole words, prenasalized regions, and vowels

3.1.2. Degree of nasalization

Tables 3 and 4 present descriptive data for nasalance averages and standard deviations in the two groups. Figure 3 shows the data for prenasalization. Finally, Table 5 presents the statistical results. Note that the word averages include the prenasalization and vowels, i.e. the measures are not independent. Subsequent data presentation will therefore focus on prenasalization and vowel data.

DV	Levene (p-value)	t-value (Welch)	Sign. level (p-value)
WdAvg	<0.001	5.3	<0.001
PreNasAvg	<0.001	7.0	<0.001
VAvg	<0.001	4.2	<0.001
PreNasDur	<0.001	3.6	<0.001
WdSD	0.613	2.9	<0.010
PreNasSD	0.244	6.2	<0.001
VSD	0.261	2.0	0.05

Table 5: Statistical results for dependent variables. Since some data did not meet assumptions for homogeneity of variance, group differences were assessed using Welch's t-test.

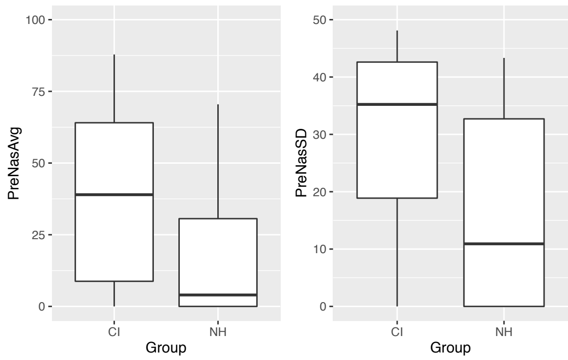

Figure 3: Group data for speaker nasalance averages (left) and standard deviations (right) in prenasalized regions

It is evident that, as a group, those with cochlear implants have higher values of average prenasalization, and greater variability in their prenasalization. It is also clear, however, that there is considerable heterogeneity within groups. As the next section will show, one should not draw the conclusion that all speakers with CIs necessarily use prenasalization to a greater degree than their NH peers.

3.2. Speaker-specific data

3.2.1. Prevalence of prevoicing

Figures 4–5 show the prenasalization data (means, SDs) broken out by speaker. In both speaker groups, average nasalance shows extreme cross-speaker variation. The standard deviations show that within-speaker variability is also quite high for some participants.

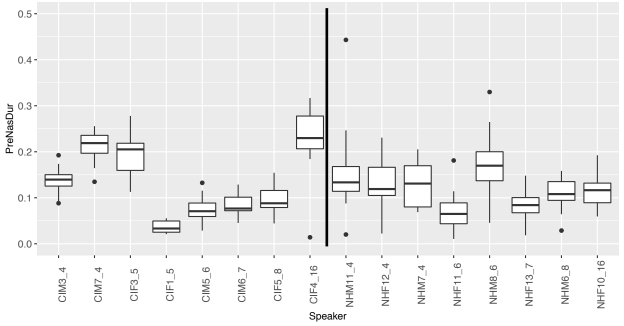

Figure 4: Individual speaker data of prenasalization averages for CI participants (left of the vertical bar) and NH participants (right of the vertical bar). Within group, participants are ordered by age.

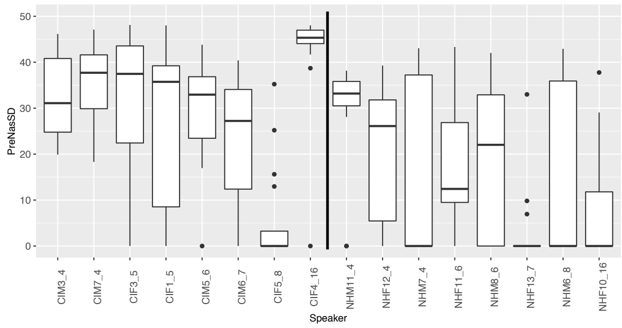

Figure 5: Individual speaker data of prenasalization standard deviations for CI participants (left of the vertical bar) and NH participants (right of the vertical bar). Within group, participants are ordered by age.

3.2.2. Coarticulation

As noted above, the word /dina/ allows assessment of both anticipatory and carryover coarticulation. Visual inspection of time-varying nasalance revealed a pattern in some of the CI children that was not observed in any of the NH children (in this modest sample): Whereas anticipatory nasalization for the medial /n/ was typical in both groups, a few children with CIs also showed extensive carryover nasality from the initial consonant. This is evident from high nasality values just after 0, the consonant release. Examples for four children, two with CIs and two NH children of similar ages, are shown in Figure 6.

4. DISCUSSION AND CONCLUSIONS

As a group, children with CIs produced somewhat less frequent prenasalization, greater magnitudes of prenasalization, and more variability of prenasalization within individual segments than their NH peers. Extensive speaker-specific variation was observed in both groups, however, and could arise from at least three sources: heterogeneity in

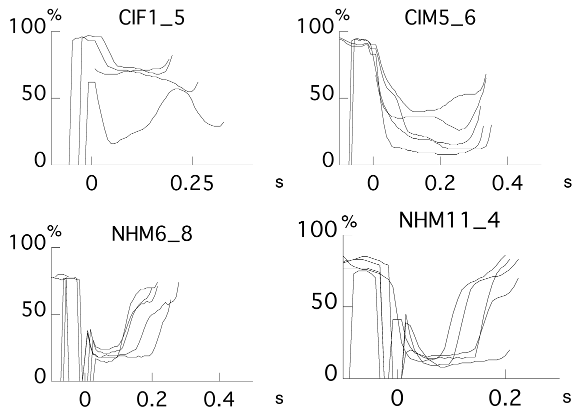

Figure 6: Nasalance over time for four participants: Two children with CIs (top) and two with NH (bottom). The y-axis shows percentage nasalance; the x-axis is time in seconds. The '0' on the x-axis represents the division between the consonant and the vowel.

development, heterogeneity within the CI population, and, possibly, dialectal variation. The proportion of prenasalized tokens did not show an apparent relationship with age. Consistent with [12], the younger NH children did tend to produce more extensive prenasalization (Figure 4), but this was not seen in the CI group. Interestingly, although many speech measures have shown decreasing variability with age (cf. [14] for a review), this was not seen for the degree of prenasalization within segments for either group (Figure 5).

The current results differ somewhat from those of [15]. That paper assessed nasalance values for medial consonants /p m n b/ in a small group of speakers (5 in each group). A group difference was observed there only for the nasals, with higher values in the CI children. That is, although that work also demonstrated a group pattern of more extensive nasalization in those with CIs, it did not extend to the one word with a *medial* prenasalized stop. Here, perhaps because of the larger dataset, a robust group difference was found for *initial* prenasalized stops. It may also be that word position is a relevant variable to explore.

As seen in much past work, group differences do not capture the speech characteristics of all children with CIs, however. Further, short-term (segmental) analyses and assessment of time-varying patterns provide a rich source of information on speech production in the CI population, and could ultimately inform intervention.

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