# Comparing short- and longer-term measures of nasal coarticulation in Greek children with cochlear implants and normal-hearing peers

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**1. Introduction.** Velopharyngeal control is difficult for at least some deaf children to master [1–3], and atypical patterns may persist subsequent to cochlear implantation (CI) [e.g., 4]. Further, some studies have reported differences in coarticulation between deaf and hearing speakers [5], which could also persist subsequent to CI. Recently [6], we compared word- and segment-level nasometer data from Greek-learning children with normal hearing [NH] and with CIs. Statistical analyses for nasalance averaged over words with medial targets showed a group effect for nasal consonants, with higher values in CI children compared to controls. However, data calculated over individual consonant and vowel regions did not show clear group differences. These results suggest that time-varying nasalance patterns, which can reflect coarticulatory influences, may indeed differ between groups. Our present goal is to carry out fine-grained analyses of nasalance values to assess possible differences in nasal coarticulation patterns between CI and NH children in short temporal windows, and compare these to previous data obtained over longer intervals.

**2. Methods**. Data were collected from eight age-matched NH-CI pairs. Children were 4–16 years of age, with all but one pair 4–8 years of age. Children produced single-word responses to pictures. We focus on the following words with target medial consonants (showing IPA and English gloss): ['tomos] *a book volume*; ['tonos] *tuna*; [zo'mos] *broth*; ['tuba] *somersault*; ['topos] *place*. The medial /p/ in ['topos] is voiceless unaspirated. The medial /b/ in ['tuba] is voiced and, for some speakers of Greek, prenasalized. Henceforth we refer to the two vowels in these disyllables as V1 and V2.

Data were collecting using the Kay Elemetrics [now Pentax] nasometer system [7]. A head-mounted stiff plastic plate rests against the upper lip, and microphones above and below the plate record low-pass-filtered oral and nasal energy. The hardware outputs a nasalance ratio ([nasal energy][oral + nasal energy]) every 8 ms.

Acoustic signals were labeled in Praat [8] to extract vowels and consonants, using overall amplitude changes and low-frequency spectral information. Time-varying nasalance values were extracted over these segmental intervals. Inspection of individual nasalance trajectories indicated that nasalance values could show large variation at the beginning of the vowel (see Figure 1). To gain a clearer picture of anticipatory and coarticulatory nasality before and after medial consonants, in this work we excerpt nasalance in smaller time windows, including, crucially, immediately before and after the target consonant (late V1 and early V2), as well as early and late in the consonant itself. Specifically, we extracted windows of 3 nasalance values, representing 24 ms (Figure 1 rectangles).

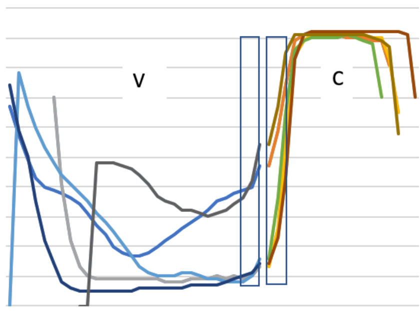


*Figure 1. Five tokens of 'tomos' produced by a 5-year-old with a CI, showing V1 and the nasal consonant. Y-axis: Nasalance, 0–100%. X-axis: Time. The vertical rectangles show the 24-ms time windows analyzed here. The variation at the far left and right of the graph reflects different vowel and consonant durations.*

**3. Results**. Preliminary analyses from 3 CI–NH pairs indicate that variability in nasalance is generally higher, and sometimes substantially so, when averaging over entire vowels and consonants vs. when assessing short time windows. Average standard deviations (SDs) are higher than single time slices in 76% and 80% of vowel and consonantal comparisons, respectively. Example data from one NH child, age 6, are shown in Table 1.

| Word | V1_avg | V1_1st | V1_2nd | V1_3rd | C1_1st | C1_2nd | C1._3rd | C_avg |
|---|---|---|---|---|---|---|---|---|
| tonos | 14.0 | 7.7 | 9.6 | 11.7 | 11.7 | 13.4 | 11.8 | 22.6 |
| tomos | 13.2 | 11.2 | 10.7 | 11.4 | 11.4 | 11.4 | 24.4 | 30.2 |
| topos | 5.4 | 5.3 | 4.9 | 3.8 | 3.8 | 2.3 | 7.2 | 5.9 |

*Table 1. Average SDs of nasalance for whole vowels (V1) and consonants and single time windows.*

Assessment of anticipatory nasal coarticulation does not currently show clear group differences; individual children with CIs may have more or less anticipatory coarticulation than hearing peers (see Figure 2).

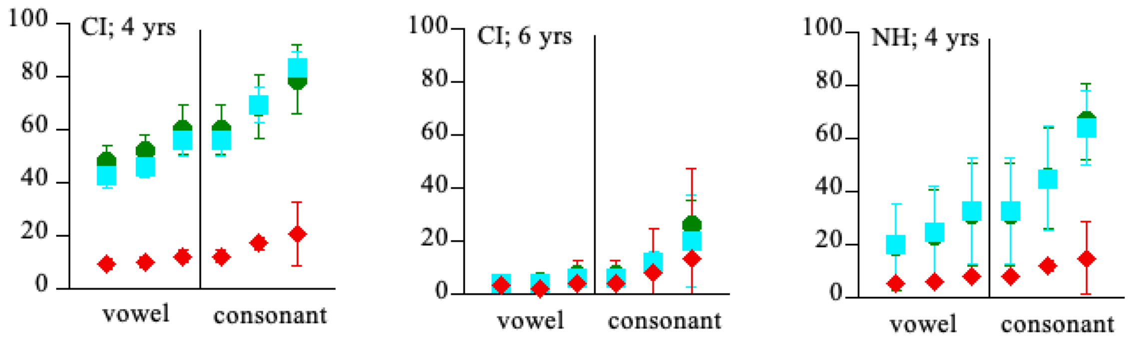


*Figure 2. More (left) and less (middle) anticipatory nasal coarticulation in children with CIs compared to an NH child (right). The y-axis is nasalance as a percentage. Blue squares, green circles, and red diamonds represent /m/, /n/, and /p/, respectively. Productions by the six-year-old CI user were sometimes but not always perceived as being oral consonants.*

**4. Discussion**. The data are consistent with past studies showing that deafness may be associated with both higher and lower nasality than typical speech. This complicates the interpretation of group-level statistics.

Nasometer data are frequently reported for long time intervals such as a reading passage [e.g., 9]. Our results indicate that nasalance data provide a rich source of time-varying information over segmental and sub-segmental levels, and moreover, that data for short time windows may show patterns not evident in longer time intervals. Our full analysis will also compare patterns of carry-over coarticulation in CI and NH children. We will also assess regions further from the consonant, calculated in absolute ms and at the temporal midpoint.

**5. References**


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