

Production of the Voicing Contrast by Greek Children with Cochlear Implants

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Abstract

Previous research has documented variability in speech production by speakers with CI. With reference to stop production, VOT duration has been reported to differ for children with Cochlear Implants (CI) and normal hearing (NH) in different languages. As the voicing contrast differs across languages, it is important to examine VOT production in the speech of individuals with CI in different languages. The Greek stop consonant inventory consists of voiceless unaspirated stops and prevoiced stops at the bilabial, dental and velar places of articulation. In this study, VOT duration is examined for voiceless and voiced word initial stops in the context of the vowel /a/ produced by 24 Greek-speaking children with CI and 24 age-matched children with NH. Results showed a tendency for longer VOT duration for the voiceless stops produced by the children with NH than with CI and longer prevoicing for the children with CI compared to their NH peers.

1 Introduction

Past research on children with profound hearing loss reported that variation in certain acoustic characteristics, such as the voicing contrast in stop consonants, impacts negatively on their speech intelligibility (Metz et al., 1990; Monsen, 1983). The speech intelligibility of children with profound hearing loss has greatly improved following cochlear implantation (Lane et al., 1995). Yet, a lot of variability in production has been observed, often attributed to several factors, such as

the age of onset of hearing loss, the age of cochlear implantation (Dunn et al., 2014; Geers et al., 2003; Fryauf-Bertschy et al., 1997) but also to factors relevant to limitations of cochlear implant technology such as inadequate processing of the spectral and fine temporal structure of speech (Oxenham and Kreft, 2014; Zeng et al., 2008; Rubinstein, 2004).

A cue of fine acoustic contrast is Voice Onset Time (VOT), defined as the temporal interval between the moment of the release of the stop and the onset of glottal pulsing. It takes positive values when the stop release precedes the onset of voicing and negative values when the stop release occurs after the onset of voicing. Values clustering at 0 ms indicate simultaneous release of the articulatory closure and the onset of vocalic voicing (Lisker and Abramson, 1964).

Previous research has shown that VOT duration differs in children with CI as compared to children with NH. (Scarbel et al., 2013) reported longer VOT durations for voiceless stops and shorter VOT values for voiced stops for French speaking children with CI compared to NH controls. They interpreted their findings to suggest exaggeration of the voicing contrast between voiced and voiceless stops by children with CI. (Aksoy et al., 2017) examined variation in VOT duration as a function of the duration of cochlear implantation. They reported VOT values for children with CI with 1 up to 8 years of implantation. Overall, shorter VOT durations were reported for all voiceless and voiced consonants for children with 1-3 years of

CI use. They also reported that longer implant use resulted in VOT durations that were closer to the NH controls.

As the voicing contrast differs across languages, it is important to examine VOT production in the speech of individuals with CI in different languages. This study aims to provide insights on VOT production by children with CI by examining data from Greek.

The Greek stop consonant inventory consists of voiceless unaspirated stops /p, t, k/ and pre-voiced stops /b, d, g/ (Arvaniti, 1999). Several studies have reported VOT duration for adult speakers of Greek (see Arvaniti, 2007 for a review) but there are few studies for children (Okalidou et al., 2010; Tsiartsioni, 2011; Chionidou and Nicolaidis, 2015). (Okalidou et al., 2010) reported VOT values ranging approximately between -140ms to -60ms for voiced stops and 10 to 50ms for voiceless stops for Greek children whose ages ranged from 2;0 to 4;0. The same study reported that Greek speaking children acquire an adult-like two-way voicing contrast, i.e. between the pre-voiced and the voiceless unaspirated stops, at all places of articulation (bilabial, dental, velar) by ages 2;6;11 (3035 months). (Tsiartsioni, 2011) examined VOT duration for Greek-speaking and English speaking children aged 10, 13 and 16 years old. VOT duration ranged between 11.98 ms to 12.85 ms for /p/, 14.29 ms to 14.83 ms for /t/, 28.89 ms to 31.86 ms for /k/, -95.90 ms to -98.68 ms for /b/, -91.40 ms to -99.99 ms for /d/ and -85.08 ms to -103.42 for /g/ for Greek. VOT duration ranged between 51.9 ms to 67.98 ms for /p/, 66.12 ms to 79.16 ms for /t/, 60 ms to 82.06 ms for /k/, -0.14 ms to -28.88 ms for /b/, -0.14 ms to -22.66 ms for /d/ and 5.72 ms to -21.10 for /g/ for English. (Chionidou and Nicolaidis, 2015) reported VOT mean values of 17 ms for [p], 17 ms for [t] and 37 ms for [k] for Greek children whose ages ranged from 8;2 to 12;6.

Furthermore previous research has examined several parameters that may have an effect on VOT production, including place of articulation, stress, and the following vowel. For voiceless stops, as articulation moves from the bilabial to the velar place of articulation the duration of VOT increases, e.g. for English (Peterson and Lehiste, 1960; Klatt, 1975; Volaitis and Miller, 1992; Cho and Ladefoged, 1999; Whiteside and Marshall, 2001; Morris et al., 2008), for Greek (Fourakis,

1986; Nicolaidis, 2002), for German (Lein et al., 2016), for Spanish (Schmidt and Flege, 1996), for Hungarian (Gósy and Ringen, 2009), for Cantonese (Tse, 2005), for Armenian and Korean (Cho and Ladefoged, 1999). On the other hand, prevoicing is longer for bilabials and dentals than velars in various languages (e.g. Helgason and Ringen, 2008 for Standard Swedish). Stress has not been found to influence the VOT duration of voiceless stops. Voiced stops tend to have longer VOT values in unstressed syllables but this difference has not been found to be statistically significant for English (Abramson and Lisker, 1964). Typically, the VOT of voiceless stops is longer when a high vowel follows than in the context of a low vowel (Lisker and Abramson, 1964, 1967; Klatt, 1975; Smith, 1978; Port and Rotunno, 1979; Morris et al., 2008; Nicolaidis, 2002).

In this study, the VOT duration of the Greek stop consonants /p, t, k, b, d, g/ in word initial position will be measured. The research questions are: a) Are there any differences in the VOT duration between Greek-speaking children with CI and NH? b) Are there any differences in VOT duration as a function of place of articulation for Greek-speaking children with CI compared to children with NH? To our knowledge, there has been no previous study examining VOT production for Greek-speaking children with CI. The study of VOT production is of theoretical and clinical importance. Clinically, the onset of voicing is usually used for the evaluation of developmental maturation of neuro-motor coordination (DiSimoni, 1974; Eguchi, 1969; Zlatin and Koenigsknecht, 1976) and constitutes an essential part of the evaluation of speech production in people with hearing loss (Monsen, 1976).

2 Method

2.1 Participants

Twenty four children with CI and twenty four age- and gender-matched children with NH participated in the study. The participants ages ranged from 2;8 to 13;3. Post-implant age ranged from 1;11 months to 11;5 (23-137 months). All participants were monolingual native speakers of Greek. In an attempt to avoid any additional effect of mental health, the Raven Test was administered; the scores for both groups ranged from 90 to 135 which is within normal limits. The speakers of the control group did not have any hearing or speech

problems as reported by their parents. Signed consent was obtained from the parents of all participants.

2.2 Material

The speech material consisted of Greek disyllabic and trisyllabic real words with word initial voiceless and voiced stops /p, t, k, b, d, g/. Stops were followed by the vowel /a/, e.g. ('papa, 'bala, 'tafos, 'dama, ka'fes, ga'raz). Stress placement was on the first or second syllable.

2.3 Procedure

A word naming task was carried out and each target word was produced at least three times in random order by all participants.

Data acquisition took place at the Cochlear Implant Center of the 1stOtorhinolaryngology Clinic of AHEPA Hospital in Thessaloniki. Data was recorded in a sound-proof booth with a SONY PCM D50 digital recorder.

2.4 Measurements

PRAAT was used for the measurement of VOT duration (www.praat.org). For voiceless stops, VOT was measured from the stop burst to the onset of the first glottal cycle and formant structure on the acoustic waveform and spectrogram respectively. For the voiced stops, VOT was measured from the first glottal cycle of the stop to the stop burst. A total of 864 tokens were produced (48 children x 6 words x 3 repetitions).

Our data didnt follow a normal distribution and violated the principle of homogeneity based on the Levenes test. Thus, non-parametric tests Mann-Whitney U test and Wilcoxon, were used for the analyses. Differences between the two groups (CI/NH) were measured.

Due to the wide range in the age of the participants, there was not homogeneity in the sample. So, further analyses were carried out on participants separated in four age subgroups by chronological age: the first group consisted of children from 2 to 4 years old (4 children in total, 2 with CI & 2 with NH), the second group ranged from 5 to 7 years old (18 children in total, 9 with CI & 9 with NH), the third group ranged from 8 to 10 years old (16 children in total, 8 with CI & 8 with NH) and the last group ranged from 11 to 13 years old (10 children in total, 5 with CI & 5 with NH).

Category	Child groups		P value	U
	NH	CI		
[voiceless]*	18.22	15.30	0.012	167.5
[voiced]	-89.45	-106.08	0.059	195.0

*p<0.05

Table 1: Mean VOT values for voiced and voiceless Greek stops produced by children with CI and with NH, n=48.

Category	Child groups		P value	U
	NH	CI		
voiceless				
[p]	15.14	12.08	0.075	201.5
[t]	12.19	9.14	0.091	205.5
[k]	27.33	24.68	0.126	214.0
voiced				
[b]	-105.97	-129.85	0.070	200.5
[d]*	-94.69	-121.10	0.009	164.5
[g]	-67.68	-67.31	0.789	274.0

*p<0.05

Table 2: Mean VOT values, p and U values for voiced and voiceless Greek stops produced by children with CI and NH as a function of place of articulation, n=48.

3 Results

All participants with CI and NH Table 1 presents mean VOT durations of the Greek voiceless and voiced stops (pooled for place of articulation) produced by all participants with CI and NH. For the voiceless stops, a statistically significant difference was found in overall VOT duration between the two groups; VOT duration was shorter in the stop productions of children with CI as compared to NH controls, $p=0.012$, $d=-0.3586$. For the voiced stops, children with CI showed longer mean prevoicing values as compared to their NH peers; however, the difference was not statistically significant. Table 2 presents mean VOT values for the stops at each place of articulation Group comparisons for each place of articulation, for the voiced and voiceless categories revealed a statistically significant difference only for the voiced alveolar stop /d/, $U=164.5$, $p=0.009$ ($d=0.36762$). In particular, mean VOT for /d/ was significantly longer for the children with CI than NH. Longer VOT was also found for /b/ for the same group; however it did not reach statistical significance. VOT duration for /g/ was similar

	R		SD			
	NH		CI		NH	CI
	Min	Max	Min	Max		
p	5	22	5	26	5.936	5.328
t	6	34	0	18	5.731	4.485
k	14	42	13	63	8.515	11.729
b	-191	-65	-404	-34	31.579	69.070
d	-153	-60	-323	0	25.341	63.097
g	-119	-29	-180	0	26.494	48.410

Table 3: Range and Standard Deviation values for voiced and voiceless Greek stops produced by children with CI and NH n=48.

for the two groups. In addition, there was a tendency for the VOT of /p, t, k/, to be shorter for the children with CI than NH although differences did not reach statistical significance. Table 3 presents the range and standard deviation values for all the stops measured.

With reference to the influence of place of articulation, a tendency for longer VOT duration for the voiceless velar stops /k/ is observed, in agreement with previous literature (Okalidou et al., 2010; Tsiartsioni, 2011; Chionidou and Nicolaidis, 2015). This is evident for both groups. For the voiced consonants, a decrease in VOT duration is evident from /b/ to /d/ to /g/ for both groups, (cf. (Tsiartsioni, 2011) for children with NH); additional statistical analyses are needed to confirm the place of articulation effect.

Group A: 2-4 years old A comparison between the two groups shows shorter VOT values for voiceless and voiced consonants for children with CI. However, no statistically significant differences were found (Table 4) ($p=0.333$, $U=0.000$, for /p/, $p=0.667$, $U=1.000$, for /t/, $p=0.667$, $U=1.000$, for /k/, $p=0.667$, $U=1.000$, for /b/, $p=1.000$, $U=2.000$, for /d/, $p=0.667$, $U=1.000$, for /g/).

Group B: 5-7 years old A comparison between the two groups shows shorter VOT values for the voiceless and longer for the voiced consonants except for the voiced velar /g/ for children with CI. However, no statistically significant differences were found (Table 4) ($p=0.279$, $U=21.000$ for /p/, $p=0.195$, $U=19.000$ for /t/, $p=0.065$, $U=14.000$ for /k/, $p=0.798$, $U=29.000$ for /b/, $p=0.083$, $U=15.000$ for /d/, $p=0.328$, $U=22.000$ for /g/).

Group C: 8-10 years old A comparison between the two groups shows shorter VOT values for the voiceless and longer for the voiced for children CI. However, no statistically significant differences were found (Table 4) ($p=0.297$, $U=28.000$ for /p/, $p=1.000$, $U=40.500$ for /t/, $p=0.863$, $U=38.500$ for /k/, $p=0.063$, $U=19.000$ for /b/, $p=0.161$, $U=24.000$ for /d/, $p=0.730$, $U=36.000$ for /g/).

Group D: 11-13 years old A comparison between the two groups shows shorter VOT values for the voiceless consonants and longer for the voiced, except for the voiceless velar /k/, for children with CI. However, no statistically significant differences were found (Table 4) ($p=0.548$, $U=9.000$ for /p/, $p=0.095$, $U=4.500$ for /t/, $p=0.1000$, $U=12.000$ for /k/, $p=0.056$, $U=3.000$ for /b/, $p=0.095$, $U=4.000$ for /d/, $p=0.095$, $U=4.000$ for /g/).

4 Discussion

Many studies have measured VOT in different languages but there is relatively limited literature for VOT duration in Greek especially with reference to children. This study contributes to current knowledge by providing VOT data for Greek-speaking children with cochlear implants.

Our results have shown significantly shorter VOT duration for the voiceless stops (pooled for place of articulation) when produced by children with CI compared to NH controls. Further analyses for each consonant separately showed that there was a tendency for shorter VOT values to be produced by children with CI for all voiceless consonants; however this difference did not reach statistical significance. With reference to the voiced stops, significantly longer prevoicing was produced for /d/ by children with CI. A similar tendency was observed for /b/ but this difference was not statistically significant.

Further analyses per age group showed that for the voiceless consonants there is a tendency for shorter VOT values produced by children with CI in all age groups. For the voiced consonants there is a tendency for longer VOT values produced by children with CI in all but the first age group (2-4 years of age). This may relate to ongoing developmental changes for this group (cf. Okalidou et al., 2010).

Differences in VOT values were observed as a function of place of articulation. Both groups

Age Group		[p]	[t]	[k]	[b]	[d]	[g]
1	NH	14.67	11.83	26.33	-146	-104.67	-77
(n=4)	CI	8.5	6.5	19.17	-127.17	-98.5	-65.33
2	NH	14.46	11.29	28.54	-117.88	-104.46	-74.83
(n=18)	CI	11.17	8.12	19.63	-140.17	-148.58	-51.33
3	NH	15.30	10.37	27.19	-97.89	-94.37	-64.33
(n=16)	CI	11.56	9.70	26.56	-132.81	-106.78	-68.11
4	NH	16.13	17.07	26.07	-85.47	-75.67	-58.53
(n=10)	CI	15.93	10.80	31.60	-109.07	-111.93	-92.20

Table 4: Mean VOT values for voiced and voiceless Greek stops produced by children with CI and NH /, for the age groups 1, 2, 3 & 4.

(CI/NH) present the same pattern in VOT for the different places of articulation. For children in all subgroups, there was a tendency for the VOT duration of voiceless stops to increase from bilabials/dentals to velars, which is consistent with previous studies reporting longer VOT duration the further back the closure is produced (Peterson and Lehiste, 1960; Klatt, 1975; Fourakis, 1986; Volaitis and Miller, 1992; Cho and Ladefoged, 1999; Whiteside and Marshall, 2001; Nicolaidis, 2002; Morris et al., 2008). For voiced consonants, there was a tendency for the VOT duration to decrease from bilabials to dentals to velars which is also in agreement with previous studies (Helgason and Ringen, 2008).

5 Conclusion

Overall our results showed a tendency for longer VOT duration for the voiceless stops produced by children with NH than CI and longer prevoicing for the children with CI compared to their NH peers. Few statistically significant differences were however found in an analysis by place of articulation and for different age subgroups.

Work currently underway aims to relate findings to the duration of CI use, to the speech perception abilities of children with CI, and to explore subject variability as well as variability due to other factors including different vowel contexts.

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