Acoustic Analysis of the Speech of an Australian English-speaking Child with Hearing Aids

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Abstract

Children with hearing loss often have problems producing adult-like consonants. This study acoustically examined the speech of a monolingual Australian English speaking 5-year-old child with bilateral severe hearing loss who uses hearing aids. The aim was to explore whether there were any systematic errors in the child's speech that may not be perceptually available to the listener. The analysis examined the acoustic cues to onset and coda segments. The results suggest that the child is making systematic errors of voicing, onset consonant place of articulation substitutions and coda consonant omissions. These findings begin to provide a baseline for designing a more controlled experimental study to explore the nature of segmental problems with the goal of designing better therapeutic interventions.

Index Terms: Acoustic phonetics, hearing aids, speech production, child language

1. Introduction

It is well known that, at an early age, typically developing children show both inter-and intra-speaker variability in the segmental realization of words (see [1] for review). Recent acoustic analysis of children's early speech productions provides insight into some of the systematic differences between child and adult speech in the acoustic cues used to signal featural/phonemic contrasts [2]. Children with hearing impairment have also been noted to have highly variable speech productions, often diverging from their typically developing peers [3]. Previous perceptual analyses of hearing impaired speech has revealed that substitution errors relating to voicing, place and manner of articulation as well as segment omissions occurred frequently [3]. However, fine-grained acoustic studies of these phenomena have yet to be carried out. The goal of this study was to conduct an acoustic analysis of a set of words produced by an Australian English-speaking child amplified with bilateral hearing aids. This would provide a more in-depth understanding of the nature of the speech problems experienced by the child, with a view to developing more effective intervention. To provide a background for the current study, the following provides a review of specific speech production problems that are known to be an issue for children with hearing impairment who use hearing aids. All studies that identified participants as aided are reported as such.

Voicing Contrasts

Varied outcomes have been reported when examining voicing contrasts in hearing impaired speech. In his 1967 study of 46 3-15 year old hearing aided children, [4] found that voiceless consonants were produced correctly more frequently than voiced consonants. However voiced consonants rather than their voiceless counterparts have also been shown to be produced more often [5, 6]. Devoicing of voiced consonants has also been reported as common [7]. However, voicing of voiceless consonants has likewise been described in similar populations [8].

Differences in voicing due to phoneme position in the word have also been observed. In comparing speech production of children with normal hearing to those with hearing loss, [9] observed that both groups showed a pattern of voicing word-initial onset stop consonants and devoicing coda stop consonants. Oller and colleagues [10] further described a tendency for their aided subjects to devoice voiced word-final coda consonants.

Phonetic context may also play a role in the varied results regarding consonant voicing. For example, in a CV+stop word, the duration of the vowel and closure preceding the stop coda will impact the perception of whether the coda is voiced or voiceless [11]. In a similar manner, voice onset time (VOT) will affect the perception of voicing. For example, Monson [12] found that children with hearing impairment had shorter VOTs than normal-hearing children for onset stops, resulting in decreased intelligibility. The children that were perceived as unintelligible were shown to have overlapping VOTs for the stop voicing contrasts.

Consonant Omission and Substitution

One study [7] observed that consonant omissions were the most common errors that severe/profoundly hearing impaired children made, whilst partially hearing children were more likely to substitute phonemes. Coda consonants were more often omitted than onsets, a finding later replicated by [6]. The stop consonants /g/ and /t/ were the most frequently omitted for both groups. Examining 65 6-year olds, [6] observed that 91% of speech production errors were due to segments being omitted. Velar consonants were the most likely to be omitted (/g/, /k/, /ŋ/) whilst consonants with a more front place of articulation (/p/ /b/ and /f/) were the most likely to be retained in both imitative and spontaneous speech. The consonants /k/, /ʒ/, /s/, /ʃ/, /z/ and /ʤ/ were among the least likely to be correctly produced, indicating that fricatives and affricates are extremely problematic for this population.

In examining 40 aided children ranging in age from 5 to 18 years, [13] noted that substitution errors were more common than omissions. Substitutions included errors of voicing (32%), manner (23%) and place (19%). The residual errors were typically substitutions involving manner and place of articulation. Markides [7] found that plosive consonants were most likely to be substituted by other plosives, including their voiced counterparts (/p/→ /b/ and /t/→/d/). Place and manner substitutions were also reported, for example /t/ → /ʧ/. Nasals and fricatives were primarily substituted with stops (/m/ → /p/, /n/ → /t/), fricatives → /t, p/.

Whilst perceptual analysis provides insight into the types of error patterns common to hearing impaired populations, there appears to be little research into speech produced by hearing impaired people using fine-grained acoustic analysis. Yet recent research on typically developing populations demonstrates that acoustic analysis is critical to providing a better understanding of the nature of children's developing phonological representations [14]. In particular, acoustic analysis may uncover cases of 'covert contrast', where child learners are making acoustic distinctions to feature contrasts that are not perceived by the adult listener [15]. If so, this could have important implications for understanding what the child 'knows' about the language being learned, providing critical information for more effective intervention.

The aim of the current study was therefore to acoustically examine the speech production of a child with pre-lingual hearing loss who is aided with bilateral hearing aids. It was hoped that the results would shed light on the nature of phonological representations in populations with hearing aids, laying the groundwork for an experimental study.

2. Method

2.1. Subject

The subject was a 5-year-old Australian English speaking female who participated in the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study [16]. The child had congenital permanent sensori-neural hearing loss diagnosed at birth, with no additional disabilities. She had been enrolled in early intervention using an aural/oral mode of communication since the age of 2.3 months. Bilateral hearing aids were first fitted at 2.6 months. At the time of testing, the hearing loss averaged over 0.5 to 4 kHz was 76dB in the right ear and 109dB in the left ear. The study was approved by institutional ethics review board.

2.2. Procedure

2.2.1. Stimuli

The Diagnostic Evaluation of Articulation and Phonology (DEAP) [17] was administered by a qualified speech pathologist according to standard protocols. The test was recorded on a digital video-recorder. A total of 50 single words (27 monosyllables and 23 polysyllables) were elicited.

2.2.2. Analysed items

Words that did not begin with a consonant were excluded from the analysis. Breathy, noisy items and words where the experimenter or parent spoke over the child's production were also excluded from analysis. The remaining items consisted of 23 monosyllables and 16 polysyllabic words. These were then further subdivided into words with simple onset consonants (n=25), onset consonant clusters (n=14), simple coda consonants (n=28) and complex coda consonants (n=2). Prosodic environment was not controlled. The limited number of items obtained for this study resulted in the inability to carry out statistical analyses. The results are therefore observational, but highly suggestive of important overall patterns to explore in future studies.

2.2.3. Acoustic coding and analysis

The data were then subjected to acoustic analysis. Acoustic coding was undertaken by a trained coder using Praat software [18]. The following acoustic events were coded, as illustrated in Figure 1: (1) Vowel Duration: The beginning and end, respectively, of a strong F2 in the spectrogram and high-amplitude regularity in the waveform, (2) Voice bar: From the point of transition from the vowel into a voice bar, characterised by less energy in the mid to high frequency range (especially in the second formant (F2)) than is seen in the preceding vowel, a simpler waveform and an abrupt loss of waveform amplitude compared to the preceding vowel, (3) Closure Duration: Measured from the end of the vowel to the left edge of the release burst, (4) Release Burst: The left edge of the coda burst signaling the release of the stop coda consonant, (5) Post Release Noise: The beginning and end, respectively, of noise associated with the release of a stop coda consonant including frication and/or aspiration, (6) Voicing: The beginning and end, respectively, of the main region of voicing including the point of transition from the vowel into the voice bar, (7) Frication: The beginning and end of frication characterised by aperiodicity in the waveform and corresponding spectral information, (8) Voice Onset Time: measured from the right edge of the release burst to the onset of periodicity. The acoustic events were then automatically extracted from Praat and subjected to analysis. Fifteen per cent of the items were acoustically recoded by a second trained coder, with 89.9% inter-coder reliability for durations and presence/absence of acoustic events.

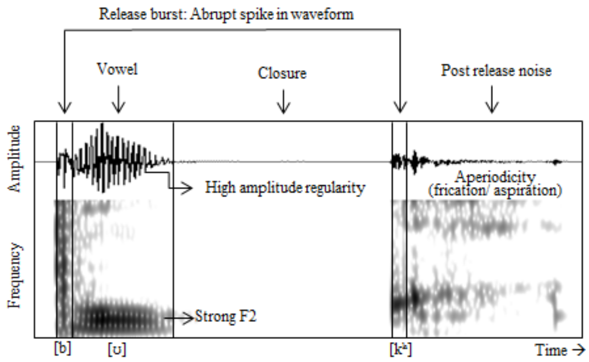

Figure 1. Spectrogram, waveform, and measures for 'book'.

3. Results

3.3.1 Perceptual transcription results

Simple onsets

Nine of 25 (36%) items had onset consonant substitutions consisting of alveolar stop → affricate (n=3), alveolar fricative → affricate (n=1) and alveolar stop → fricative (n=1) substitutions. In addition, there were dental and labiodental fricative → stop (n=3) and alveolar fricative → stop (n=1) substitutions. These transcriptions are provided in Table 1.

For affricate substitutions, place of articulation is typically maintained, whilst the manner of articulation is altered. Dental/labiodental stop substitutions involved mostly manner and place changes, with two occasions of +voice addition. The alveolar fricative was substituted with the stop, maintaining the same voicing. There were no cases of onset consonant omission, as shown in Table 2.

Complex onsets

Five of 14 items (35.7%) had substitutions and 3 of 14 (21.4%) items showed simplification. Substitution only items consisted of [/sk/→/sg/] and [/s/→/ʧ/]. Alveolar stop/fricatives showed a similar pattern of affricate substitutions as the simple onset consonants (e.g. /s/→/ʧ/). Cluster simplification involved reduction [/pr/ → /p/] (n=1), and there were some cases of both simplification and substitution [/tr/ →/ʧ/] (which may be the percept of a retracted /t/ and devoiced /r/), [/sp/ → /b/] (which may be the result of the unaspirated /p/) and [/str/ → /ʧ/]. These processes are shown in Table 1.

Simple codas
In contrast to onsets, which were all preserved, 8 of 28 (28.6%) cases of coda consonants were omitted (see Table 2). Five alveolar codas were omitted, including /t/ (n=1), /l/ (n=1) and /n/ (n=3). Three of 4 (75%) dental/labiodental fricatives were omitted (/v/ (n=1), /f/ (n=1) and /θ/ (n=1)). There were 5 cases of stop → fricative substitution, 4 of which involved devoicing. There was 1 case of /s/ → /ʃ/ substitution.

Complex codas
Out of 2 items (Table 2), there was 1 case of cluster simplification [/vz/ → /v/]. However, this may be due to the child inserting ‘a’ before the item ‘gloves’ resulting in the production ‘a glove’ /ə glɐv/. The child omitted the coda cluster /ts/ in ‘biscuits’. Since previous findings have noted that coda consonants are less perceptually salient than onset consonants due to differences in coarticulation and amplitude (also fundamental frequency for voiced consonants) [18], and /s/ is a problematic phoneme for children with hearing loss due to the limited percept of spectral information [6], it is not surprising that it was omitted in the complex coda clusters. It is interesting nonetheless to determine if there is any acoustic trace in the /ts/ omission that may be suggestive of a mental representation of /s/.

A summary of all the findings is provided in Figure 2.

Table 1. Consonant substitutions

Simple onset		**Complex onset**	
Orthography	*IPA*	*Orthography*	*IPA*
scissors	[ʧɪzəs]	train	[ʧæɪ]
teeth	[ʧi:]	splash	[blæʃ]
tiger	[ʧɑegɐ:]	square	[sgwe:]
toothbrush	[ʧʉ:brɐʃ]	swing	[ʧwɪŋ]
thank you	[dænkʉ:]	strawberry	[ʧo:bæwi:]
this	[gɪʃ]		
zebra	[debwə]		
fishing	[bɪʃɪŋ]		
tomato	[səmɐ:təʉ]		
Simple coda		**Complex coda**	
Orthography	*Transcription*	*Orthography*	*Transcription*
frog	[fok]	n/a	
pig	[pɪkʰ]		
crab	[kɹ̥æp]		
this	[gɪʃ]		
scissors	[ʧɪzəs]		

Table 2. Consonant omissions

Simple onset		**Complex onset**	
Orthography	*Transcription*	*Orthography*	*Transcription*
n/a		n/a	
Simple coda		**Complex coda**	
Orthography	*Transcription*	*Orthography*	*Transcription*
five	[fɑe]	biscuits	[bɪʃgə]
queen	[kwi:]	gloves	[glɐv]
school	[skʉ:]		
teeth	[ʧi:]		
train	[ʧæɪ]		
van	[væ:]		
giraffe	[ʤjɐ:]		
rabbit	[ræbə]		

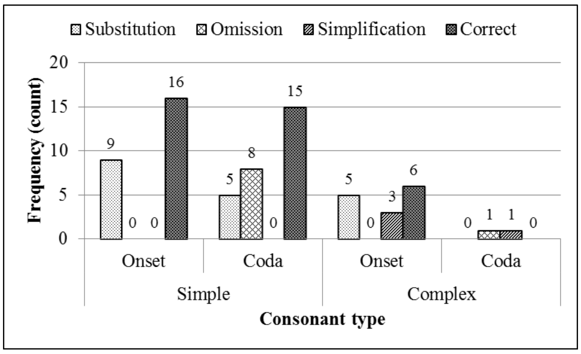

Figure 2. Number of substitutions, omissions and correct items in simple and complex onsets and codas

3.3.2 Acoustic results

Simple onset consonants
Voice onset time (VOT) was measured for simple stop onset consonants. Due to the limited number of items, voiced stops /b/ and /d/ were averaged, as were the voiceless stops /k/ and /p/. The average VOT for the voiced stops was 6.65ms and the average for the voiceless stops was 67ms. /t/ was always affricated (/t/ → /ʧ/) and was not considered a stop. Thus, the child appears to be using VOT to mark voicing contrasts in stop onsets, and perceptually, this was the case.

Simple coda consonants
Voice bar, which is often (though not always) present in the context of a voiced coda stop in typically developing child and adult speech [2], was used in 1 of 3 (33.3%) occasions. This may contribute to the confusion regarding the coda voicing. Irregular pitch periods and noise at the end of vowels have also been reported as possible cues to stop coda realization in typically developing child productions [2]. The child had one case where irregular pitch periods may have been used to reinforce the stop coda (‘sheep’) and 4 occasions of vowel final noise where the stop coda was omitted. The child may be using these covert cues to signal coda realization. There was no acoustic trace for the child’s omission of the coda cluster /ts/ in ‘biscuits’. Interestingly, stop coda release bursts were apparent in all monosyllabic words.

The durations for vowels, closure and post-release noise were investigated in the short vowel monosyllables ending with a stop coda. Items with a target voiceless coda had preceding vowels that were shorter compared to the voiced coda condition (61.5ms vs. 152ms, respectively). Closure durations were comparable between the two (135ms vs. 138.2ms) and post-release noise appeared to vary significantly (112ms vs. 47.5ms). Interestingly, all of the target voiced codas were perceptually coded as voiceless, an issue that will be interesting to investigate further with more subjects.

The child also produced coda consonants more reliably (6 of 7, 85.7%) when preceded by a short vowel than by a long vowel (1 of 4, 25%), consistent with previous findings of typically developing children [19, 20].

4. Discussion

The most notable finding from this case study is the different realization of onset compared to coda consonants. The child did not omit any onset consonants, whereas coda consonants were frequently omitted (28.6%). This is consistent with previous findings [7] including the specific omission of fricative codas [6].

Consonant substitution was found for both onsets and codas, however onsets were substituted to a greater degree than coda consonants (35.9% vs. 17.8%). Onset consonants have been reported to be more perceptually salient than coda consonants [21]. This suggests that the child may perceive an onset consonant to a greater degree than a coda consonant and subsequently produce onset consonants more consistently.

There is an apparent pattern of onset substitution in relation to the alveolar place of articulation. For both simple and complex onset consonants, the child's substitutions were often due to a manner change only, where alveolar stops and fricatives became affricated. Markides [7] reported a similar finding where /t/ → /ʧ/ yet the possible perceptual and/or articulatory reasons for this are not entirely clear. Moreover, the child tends to produce voiced consonants in onset position, contrary to the findings of [5, 6].

In contrast to onset position, the child tended to produce voiceless consonants in coda position. This is consistent with reports by [10], and is sometimes reported in the speech of typically developing children as well [22]. Acoustic analysis did not reveal why voiced coda consonants were perceptually voiceless. This question remains to be addressed in future research.

5. Conclusion

This case study provides a first examination of systematic errors and covert acoustic cues to onset and coda realizations produced by a child with hearing aids. In so doing, it provides the baseline for a more controlled experimental study, holding important implications for intervention.

6. Acknowledgements

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