IS THERE COMPENSATORY VOWEL LENGTHENING IN THE LANGUAGE ACQUISITION OF A CHILD WITH A COCHLEAR IMPLANT

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ABSTRACT

Compensatory vowel lengthening (CVL) is found in both adult and children's language. CVL is a process where the loss of a segment is compensated elsewhere by lengthening. It occurs mostly in languages with phonemic vowel length (de Chene and Anderson 1979). We examine CVL in the acquisition of Israeli Hebrew (IH), a language without phonemic vowel length, in a child with a cochlear implant (CI). Preliminary findings reveal: (1) a preference for the vowel /a/; (2) longer vowel duration before: (a) sonorant codas than obstruent codas; and (b) deleted sonorant codas than before preserved sonorant codas and open syllables. There is no significant difference in vowel duration before preserved and deleted obstruent codas and open syllables. We hypothesize that CVL appears in IH-speaking children but in sonorant codas only. The findings are discussed in terms of the representation of CVL in children's grammars as well as auditory deprivation, which may affect auditory perception and motor coordination.

KEYWORDS: Compensatory vowel lengthening; cochlear implant; coda deletion; moraic representation; motor coordination.

1. Introduction

1.1. Syllable weight

Languages differ in the constraints they place on syllable weight, i.e. the distinction between "heavy" and "light" syllables. In all languages, a syllable with only a short (lax) vowel in the syllable rhyme (CV) is light (Figure 1a) and a syllable with a long vowel (CV:) is heavy (Figure 1b). Languages differ however in the way they treat a syllable

with a short (lax) vowel followed by a consonant (CVC). Some languages (e.g. Latin, most dialects of Arabic, Hindi, and to some extent English) treat such a syllable as heavy (Figure 1d), while others (e.g. Huasteco, Malayalam, and Khalka Mongolian) treat it as light (Figure 1c) (Hyman 1985). Gordon (2006) identified 136 out of 408 languages with weight-sensitive stress systems. Of these 136 languages, he found 42 that treat CVC as heavy and 35 that treat CVC as light.

No language has been found which defines a VC syllable rhyme as heavy, but a long vowel V: syllable rhyme as light (Hyman 1985). In addition, although a language lacking VC syllable rhymes may define V: as heavy and V as light (e.g. Maori) (cf. Hohepa 1967: 10), no language lacking V: syllable rhymes but having VC syllable rhymes defines the latter as heavy. In other words, in order for a VC syllable rhyme to be counted as heavy, the language must also have V: syllable rhyme (Trubetzkoy 1939). Syllable weight is thus obligatorily connected to the existence of a vowel length (or vowel tenseness) opposition.
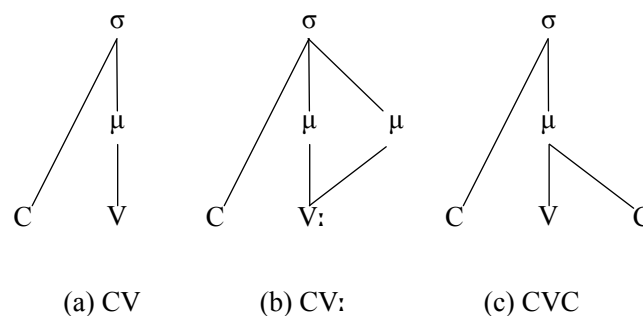

Figure 1. Syllable weight: (a) light syllable; (b) heavy syllable; (c) light syllable.
σ = Syllable. μ = Mora.

Figure 1 presents four types of syllable weight at the mora level. The mora is the lowest level in the prosodic hierarchy. It represents the notion of syllable weight and it constitutes the syllable rhyme. Light syllables (e.g. /ki/) have one mora (the nucleus /i/), while heavy syllables (e.g. /kik/) have two moras (the nucleus /i/ and the coda /k/) (Hyman 1985; Hayes 1986). According to Figure 1a, a light syllable consists of a short (lax) vowel dominated by one mora while a heavy syllable (Figure 1b) consists of long (tense) vowels dominated by two moras. However, there are languages in which CVC is defined as heavy, i.e. CVC is assigned two moras (Figure 1d), while in other languages CVC is defined as light, i.e. is assigned only one mora (Figure 1c). Moreover, in some languages only a subset of the consonants makes their syllable heavy when they occur in coda position (Hyman 1985; Gordon 2002a).

1.2. Compensatory vowel lengthening

Compensatory vowel lengthening (CVL) is a familiar process in adult language (Hayes 1989) as well as in children's speech (Fikkert 1994; Demuth and Fee 1995; Ota 1999; Kehoe and Lleó 2003). It is defined as a mechanism in which the loss of a segment is compensated elsewhere in the output through a process of lengthening (Hayes 1989). For example: deletion of a consonant leads to lengthening of the preceding vowel. In CVL following consonant deletion, the mora projected by the consonant is left stranded by the segment deletion, and re-associates itself with the preceding vowel, which carries two moras as a consequence. Below are a few examples of CVL from various languages in which a segment takes the position of the adjacent deleted segment, and thus becomes long.

(1a)   Turkish (Sezer 1986)

        kahya ~ kaːya 'steward'
        seyret ~ seːret 'watch'

(1b)   Greek (Wetzels 1986)

        Ancient Greek   Lesbian/Thessalian   Other dialects
        *klin+yoː   >   klinnoː   >   kliːnoː   'tend'
        *kten+yoː   >   ktennoː   >   kteːnoː   'kill'

(1c)   Tiberian Hebrew (Lowenstamm and Kaye 1986)

        haggešem   'the rain'   but   haːʕam   'the nation'
        nagger   'carpenter'   but   paːraš   'horseman'

As can be seen from the examples above, a segment (e.g. /y/ in the first example in Turkish) was deleted before another segment (i.e. /r/). When the deleted segment followed a vowel (i.e. /e/), the vowel became long (i.e. /eː/). The process of CVL in Turkish is presented in Figure 2.
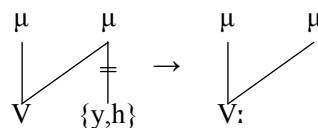

Figure 2. The process of CVL in the examples from Turkish.

The condition for CVL to occur is that deletion must create an empty prosodic/ phonological position. This phenomenon has been mainly reported in languages sensitive to syllable weight (e.g. Japanese; Dutch; English; French and German).

1.3. Compensatory vowel lengthening in language acquisition

Studies of the acquisition of vowel lengthening indicate an initial stage in which phonological vowel length is random, followed by a second stage in which either long vowels (without coda) or short vowels and codas are produced. These findings are reported in languages such as Japanese (Ota 1999), English (Demuth and Fee 1995; Bernhardt and Stemberger 1998; Stemberger 1992b), Dutch (Fikkert 1994), and German (Kehoe and Lleó 2003). Children acquiring these languages show moraic preservation in the second stage, preserving minimal word targets as binary feet,[1] i.e. they produce the word either with short vowel and coda or lengthen the vowel to two moras if they cannot produce word-final consonants, thus preserve the mora position.

Ota (1999), for example, found that codas took some time to be acquired. However, rather than simply omitting these segments, 1-2 year old Japanese–speaking children showed evidence of CVL when nasal codas or diphthongs are deleted, actual lengthening the vowel to two moras (e.g. [woːwɔ:] for /waɴwaɴ/ 'doggie').Thus, it appears that Japanese children are attuned to the moraic structure of their language, employing CVL as a means of preserving moraic structure when they do not produce coda consonants.

CVL triggered by loss of codas is also reported in other languages. In a study of Dutch phonological development, Fikkert (1994) showed that once phonemic vowel length contrasts became stable, the deletion of a target sonorant coda often lengthened the preceding short vowel (e.g. [boː] for /bal/ 'ball'). Stemberger (1992b) observed CVL in an English-speaking child. When the child deleted the coda consonant, she tended to change a target short vowel to a long tense vowel. Moreover, she also showed CVL triggered by diphthong reduction. Demuth and Fee (1995) suggest that if children cannot produce a binary foot by preserving the coda, adjustment processes, such as CVL will be used to meet word minimality constraints.

1.4. The vowel system in young children with cochlear implants

Vowel features are among the most readily perceived phonemic cues for prelingually deaf children who receive CI (Boothroyd 1991; Geers and Brenner 1994; Miyamoto et al. 1993). Studies have shown that deaf children improve vowel production accuracy following implantation (Ertmer et al. 1997; Tye-Murray and Kirk 1993; Tobey and Geer 1995; Tobey et al. 1994).

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[1] A binary foot contains two syllables or two moras. Since our discussion refers to the initial stage of word acquisition we refer to a bimoraic binary foot.

Ertmer (2001) described changes in vowel production by a congenitally deaf child who received a CI at 19 months. The follow-up began a month before implantation and continued 12 months after implantation. The child appeared to have made substantial progress in her vowel system during the first year of implant use in terms of rate and completeness: (i) her vowel inventory more than doubled after 2 months of implant experience (from 2 to 5 vowel types), and a total of 9 different vowel types were observed during her first year of implant experience; (ii) acoustic analyses revealed that the child's vowel space was near normal in size and the formant structure of /i/ and /u/ were distinctive from other point vowels. Increased number of vowel types relatively soon after implantation is also reported in the Ertmer et al. (2002) study. Moreover, whereas no phonemic diphthongs were noted during the pre-implantation of the two English-speaking children with a CI in their study, the children's inventory included the three phonemic diphthongs of English (i.e. /aɪ/, /aʊ/, and /ɔɪ/) after 10 months of implant experience. Ertmer et al. (2002) explained that the emergence of phonemic diphthongs may suggest that improved hearing sensitivity was important for establishing control over rapid diphthongal articulatory movements. The data in the above study indicated that increases in the diversity of vowel and diphthongs were among the first signs of benefit from cochlear implantation. The early emergence of these sounds suggests that they were perceptually salient and relatively easy to produce given the signal from the implant.

1.5. Is there a compensatory vowel lengthening in the acquisition of Israeli Hebrew?

Israeli Hebrew (IH)[2] does not have a phonemic vowel length contrast, and there are no reports of long vowels in the speech of hearing IH-acquiring children. Furthermore, there is no evidence for the significance of syllable weight, thus there is no evidence in IH that the coda is moraic (Adam 2002).

Since it is generally assumed that the unmarked syllable is mono-moraic, and that children construct bimoraic syllables only when they receive positive evidence from their ambient language (Fikkert 1994; cf. Hayes' 1989 "weight by position"), one does not expect to find CVL in the speech of IH-acquiring children.

However, Adi-Bensaid and Bat-El (2004) reported that a IH-speaking child with a CI produced long vowels in 57% of the target syllables with a coda (17 out of 30 tokens) during the initial stage of language acquisition (~1;5years) (e.g. [iː] for /pil/ 'elephant', [aː] for /af/ 'nose', /xam/ 'hot' and /an/ 'car sound', and also [ˈmaiː] for /ˈmaim/ 'water'). This number dropped to an average of 25% in the following stages (30 out of 128 in the minimal word stage (~2;1 years) and 37 out of 144 in the pre-final stage

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[2] Lately, the definition of the Hebrew spoken in Israel has become a controversial issue (i.e. Modern Hebrew, Contemporary Hebrew, Israeli Hebrew or even Israeli). For a broad discussion of this issue, see Tobin (2009b). We use the term Israeli Hebrew (IH) throughout this article.

(~2;6 years). There were no words with a long vowel in the final stage (2;9 years). The authors assumed that a long vowel compensates for a missing prosodic unit to the right of the syllable produced by the child, where the missing unit is either a coda or a syllable. It should be mentioned, however, that the analysis of this study was based on transcription only, with no acoustic analysis, a fact that led to the current study.

In the languages noted in the previous section, there is independent evidence for moraic structure, i.e. phonemic length contrast, and thus CVL in the children's speech may be due to language-specific structure, through a universal constraint of preservation of prosodic structure.

However, in contrast to the languages discussed above, IH does not exhibit phonemic vowel length, nor is there a phonological process that suggests moraic structure; therefore the findings of Adi-Bendsaid and Bat-El are surprising. Thus, the purpose of the present study is to examine vowel length in various phonological environments in the speech of an IH-speaking child with a CI in the beginning of language acquisition using acoustic analysis.

2.   Method

2.1. Participant

The empirical basis of this study is drawn from the speech of a monolingual deaf IH-speaking boy using a CI device. The child had a bilateral profound sensorineural hearing loss of unknown etiology. At the age of 5 months, he was fitted with a binaural personal conventional hearing aid (Phonak E-4). His aided thresholds were 80 dB HL in the right ear and 75 dB HL in the left ear (these levels represent the pure tone average of 500, 1000, and 2000 Hz). His hearing aids improved his auditory awareness to environmental and speech sounds. However, he received a CI because he derived negligible benefit from the conventional hearing aids and had no functional hearing. By the age of 1;2, he was implanted (Nucleus 24) in his left ear. The CI lowered his auditory threshold for speech to 25–30 dB HL. Thus, more speech sounds became audible to him and he was able to detect, discriminate, identify, and understand more speech stimuli in conventional speech perception tests conducted in the clinic. The child had hearing parents and he used oral communication only.

2.2. Procedure

The data presented in this paper represent a sample from a large data base (Adi-Bensaid 2006) which includes 243 tokens of the child's speech (for 47 target words), collected during 15 recording sessions of 45 minutes each; the first session was at the age of 1;5 and the last at the age of 2;4 years. The elicitation was based on both spontaneous

speech and picture and object naming. All the recordings were transcribed by the first author. Five audiotape recording sessions of the child were selected at random and a second examiner transcribed the sample records independently. The fact that there was a high level (85%) of agreement between the examiners regarding the transcription reflected a high degree of inter-judge measurement reliability.

2.3. Database and acoustic analysis

The database consists of monosyllabic word productions of mono- and polysyllabic target words. To avoid stress effects on vowel length (Most et al. 2000; Bennett 1981), disyllabic words were not included in the database, even though they existed in the child's lexicon.

The child's monosyllabic productions were selected and organized according to the following criteria. All these criteria took into account for the five vowels of IH (i.e. /a, ɛ, i, o, u/):

– Monosyllabic productions with obstruent coda for target words with obstruent coda (e.g. [af] and [ap] for /af/ 'nose');
– Monosyllabic productions with sonorant coda for target words with sonorant coda (e.g. [day] for /day/ 'enough');
– Coda-less productions for target words with obstruent coda (e.g. [a] for /af/ 'nose' and /op/ 'hop');
– Coda-less productions for target words with obstruent coda (e.g. [a] for /an/ 'car noise' and /oɣ/ 'light');
– Coda-less productions for coda-less target words (i.e. CV structure) (e.g. [pa] for /po/ 'here', [a] for /lo/ 'no');
– Monosyllabic productions for disyllabic and polysyllabic target words (e.g. [ba] for /buˈba/ 'doll', [ma] for /ˈima/ 'mammy').

Data were analyzed acoustically using the Praat software program (Boersma and Weenink 2009). Vowel duration of all monosyllabic productions was measured. Both the time wave form and spectrographic display were used to aid measurement. In order to measure vowel duration, the cursor was placed at both the starting and ending points of the observed formant structure. Duration was measured from the onset of F_2 to the offset of F_1 (Kehoe and Lleó 2003). The location of the cursor was also determined by relying on acoustic cues in the spectrogram of each group of consonants: vowel length before obstruents (i.e. stops and fricatives) was measured by also using the acoustic cues of the salience period of the stops (as well as the burst immediately after) and the continuant noise of the fricatives following the vowel. However, since sonorant segments

are voiced,[3] vowel length before the sonorants[4] was also measured by relying on three acoustic cues: (i) the falling from the relatively higher F_1 of the vowel /a/[5] (760 Hz approximately) to the following relatively lower F_1 (or nasal murmur) of the nasals (230 Hz approximately) as well as the glides (310 Hz approximately); (ii) the relatively lower intensity of F_2 of the nasals and glides in comparison to that of the preceding vowel; (iii) the sliding feature of the glides as opposed to the steady state of the vowel (Ladefoged 2001).

3. Results

3.1. The child's productions according to vowel type

Table 1 presents the number of target words and the child's productions according to vowel type.

Table 1. Target words and child's productions according to vowel type.

Target word	Child's production					
Vowel	Total	a	ɛ	i	o	u
a	77	77				
ɛ	40	5	35			
i	11		5	6		
o	78	42			36	
u	3	1				2
Polysyllabic	47	38		7	1	1
Total	256	163	40	13	37	3

Target words: it is evident from Table 1 that most of the monosyllabic target words contain the vowels /a/ (77 out of 209 = 36.8%) and /o/ (78 out of 209 = 37.3%). The vowel /ɛ/ is less frequent (40 out of 209 = 19.1%) Finally, the vowels /i/ and /u/ are very rare (11 out of 209 = 5.3% for /i/, and 3 out of 209 = 1.4% for /u/).

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[3] Nasals as well as the lateral approximant /l/ are acoustically similar to vowels and have formants, and the acoustic cues of glides such as /w/ and /y/ occur within transitions to and/or within the vowel formants themselves (Ladefoged 2001; Tobin 1997).

[4] The sonorant coda preserved by the child included only nasals (i.e. [m, n]) and glides (i.e. [w, y]). Liquid consonants (i.e. [l] and [ɹ]) are often problematic for young IH-speaking children as in other languages (e.g. Smit 1993; Kehoe and Stoel-Gammon 2001 for English) and acquired late. Thus, the child in this study produced no target liquid codas during the recording session of this study.

[5] Since most of the data contained words with the vowel /a/ and there were very few tokens with the other vowels, all the statistics analysis presented from now on relate to the vowel /a/ only. Thus, the data of /a/ includes 163 tokens of the child's speech for 34 target words.

Child productions: The child's productions, therefore, reveal a prominent preference for the vowel /a/ (163 out of 256 = 63.7%); less preference for the vowels /o/ (37 out of 256 = 14.45%) and /ɛ/ (40 out of 256 = 15.6%); and infrequent productions of the vowel /i/ (13 out of 256= 5%) and /u/ (3 out of 256 = 1.4%). In other words, when the child replaced the vowel of the target word, he preferred producing the vowel /a/ instead of the target vowel (i.e. 48 out of 53 = 90.5% of the replaced vowel are /a/). The vowel productions are presented in Figure 3.
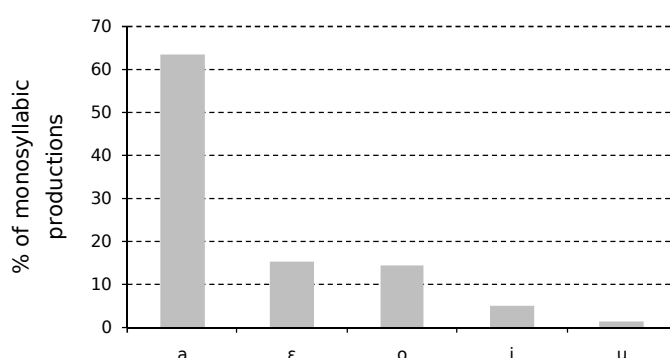

Figure 3. Vowel production.

The preference for syllables with the vowel /a/ also appeared in the disyllabic and polysyllabic word productions. In most cases (38 out of 43 polysyllabic tokens = 88.4%), the child selected the syllables with the vowel /a/ and deleted the syllables with the other vowels whether it was stressed or unstressed. In other words, the child deleted the syllable with the vowel /a/ in 2 out of 29 target words with /a/ in the stressed syllable (6.9%). Also, he deleted the syllable with the vowel /a/ in 3 out of 14 words with /a/ in the unstressed syllable (21.4%).

3.2. Vowel duration before sonorant vs. obstruent, coda either preserved or deleted

As expected, vowel duration before sonorant codas was longer than before obstruent codas (Mean = 0.24 sec. vs. 0.175 sec. respectively). Two sample t-test indicated a significant difference between vowel duration before sonorant and obstruent codas[6] (t =

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[6] Distinction between words with voiced vs. voiceless obstruent coda was not made because of lack of data, which did not enable statistical analysis. This lack of data has a phonological origin based on the historical allophonic spirantisation of stops in final position found in earlier stages of Hebrew which has been preserved in the lexicon of IH where the same stops and fricatives are phonemes today (Tobin 1997: chap. 5).

2.26, df = 10.3, p = 0.046). Furthermore, there was a significant difference between vowel duration before *deleted* sonorant codas (Mean = 0.503 sec.) in comparison to *deleted* obstruent codas (Mean = 0.255 sec.) (t = −3.15, df = 25.8, p = 0.0041) (Figure 4).
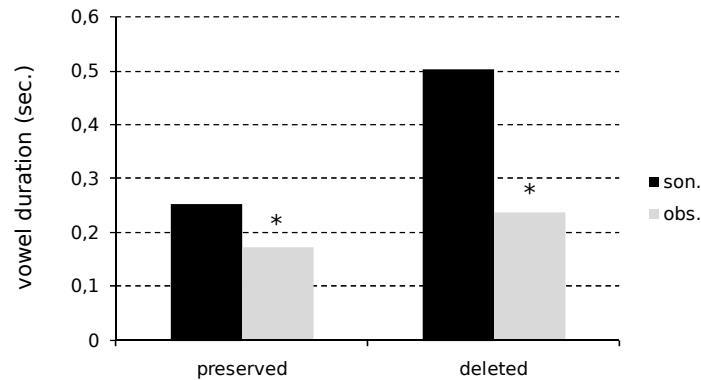

Figure 4. Vowel duration: Sonorant vs. obstruent codas.

3.3. Vowel duration before deleted codas vs. preserved codas

Two sample t-tests indicated a significant difference between vowel duration before deleted sonorant codas (Mean = 0.503 sec.) in comparison to preserved sonorant codas (Mean = 0.24 sec.) (t = 3.46, df = 22.9, p = 0.0021) and to open syllables (CV) (Mean = 0.242 sec.) (t = 3.41, df = 23.5, p = 0.0024). However, there was no significant difference between vowel duration before deleted obstruent codas (Mean = 0.255 sec.) in comparison to preserved obstruent codas (Mean = 0.175 sec., p = 0.03) and open syllables (CV) (Mean = 0.242 sec., p>0.05) (Figure 5).
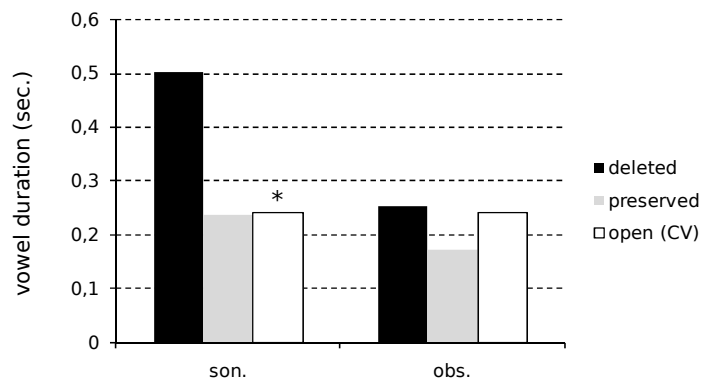

Figure 5. Vowel duration: Deleted vs. preserved coda and an open syllable.

3.4. Vowel duration in disyllabic and polysyllabic target words

A comparison between vowel duration in monosyllabic productions of disyllabic and polysyllabic targets and vowel duration of monosyllabic targets both with and without codas is presented in Table 2.

Table 2. Vowel duration in polysyllabic target words.

Production	Target words		p
	Polysyllabic	Monosyllabic	
Monosyllabic without Coda [(C)V]	0.342* sec	0.242* sec	0.0048
Monosyllabic with son. Coda [(C)VCs]	0.370** sec	0.240** sec	0.0032

*   For example: [pa] for /naˈfal/ 'fall dawn' ms. vs. [pa] for /po/ 'here'
**   For example: [bam] for /baˈlon/ 'balloon' vs. [day] for /day/ 'enough'.

As can be seen from Table 2, vowel duration was significantly longer in monosyllabic productions of disyllabic and polysyllabic targets in comparison to monosyllabic targets both with sonorant codas (t = 3.14, df = 40, p = 0.0032) and without codas (t = 3.46, df = 71, p = 0.0048).

3.5. Vowel duration before deleted coda vs. deleted syllable

There was not a significant difference between vowel duration before deleted codas in monosyllabic targets (e.g. [ya] for /yad/ 'hand', and [aː] for /xam/ 'hot') (Mean = 0.342 sec.) than in deleted syllable in disyllabic and polysyllabic targets (e.g. [ma] for /nigˈmaɣ/ 'finished') (Mean = 0.360 sec., p>0.05).

3.6. Changes in vowel duration over time

As reported in the Procedure section, the data presented in this paper were collected over a period of almost a year. Figure 6 presents vowel duration before deleted sonorant codas, deleted obstruent codas, and open syllables (CV) for each month of the recording sessions. As can be seen from Figure 6, the significant changes in vowel duration occurred before deleted sonorant codas, characterizing a decrease in vowel duration over time. Less changes in vowel duration occurred before deleted obstruent codas and open syllables.
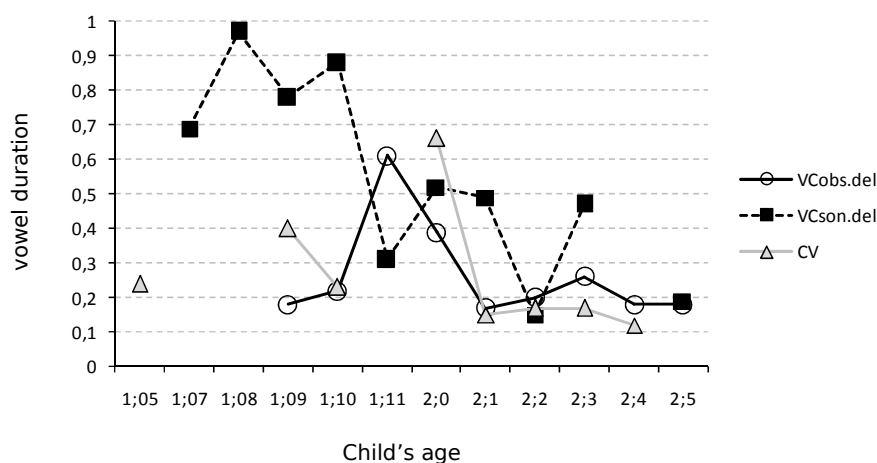
Figure 6. Changes in vowel duration over time.

4. Discussion

The purpose of the present study was to examine vowel length in various phonological environments in the speech of an IH-speaking child with a CI in the beginning stage of language acquisition using acoustic analysis.

The initial findings reveal that the vowel /a/ was the most frequent vowel both in targets and productions. The high frequency of /a/ in the data reflects its high frequency in IH and across languages. According to principles of the theory of Phonology as Human Behavior (PHB) in phonemes of aperture (vowels) – maximal aperture is preferred (/a/), and in phonemes of stricture (consonants) – maximal stricture is preferred (stops) (Tobin 1997, 2009a).

In the 5667 disyllabic nouns (the most common of IH stems), the frequency of /a/ is 36%, and the other vowels it is 22.5% for /i/, 17% for /ɛ/, 14.5% for /u/, and 10.5% for /o/ (based on the IH dictionary compiled by Bolozky and coded by Becker; Bolozky and Becker 2006). Thus, the child reflects the preference for /a/ in both attempts and productions (as in Adam 2002; Adam and Bat-El 2007). The preference for syllables with the vowel /a/ also appeared in the disyllabic and polysyllabic word productions. In most cases (80.85%), the child selected the syllables with the vowel /a/ and deleted the syllables with the other vowels whether it was stressed or unstressed (e.g. [bam] or [baw] for /baˈlon/ 'balloon', [ma] for /ˈima/ 'mammy' and also [bam] for /bakˈbuk/ 'bottle'). These findings support other studies (Adam 2002; Adi-Bensaid 2006). Adam (2002) noted that this preference could be a result of segmental effects. Based on Levelt (1994), Adam proposes that children's production during the initial acquisition stages is affected by vowel features rather than by the prosodic properties

of the syllables. The only vowels the children in Adam's (2002) study produced at this stage were /a/ and /u/, with these vowels being faithful to those of the target syllables they chose to produce, with a preference for /a/ over /u/ (e.g. [ka] for /ˈmuzika/ 'music' as well as for /kaˈduɣ/ 'ball', and also, [ba] for /baˈlon/ 'balloon', as well as for /ˈbambi/ 'Bambi' and /buˈba/ 'doll'). The production of /i/ and /u/ might be related to the arrangement of electrodes that convey information about F_1 and F_2 for these vowels (Tye-Murray and Kirk 1993).

The vowel /a/ is the most salient vowel because it is: (a) longer than the other vowels (Most et al. 2000); (b) the loudest vowel; and (c) the most sonorous vowel (Tobin 1997; Ladefoged 2001). These features are easily perceived by deaf children and thus were easily perceived by the child with a CI in the current study.

The second finding revealed that vowel duration before sonorant codas was significantly longer than before obstruent coda (both deleted and preserved). This might be due to the fact that, like vowels, sonorant consonants are voiced and continuous (Ladefoged 2001; Tobin 1997) and may even have formants,[7] thus they enable the speaker to lengthen vowels naturally before voiced sonorants without making any additional laryngeal gestures (Tobin 1997, 2002, 2009a).

The third finding revealed that vowel duration was significantly longer before deleted sonorant codas than before preserved sonorant codas as well as open syllables (a). The main difference in vowel duration occurred before deleted sonorant codas, characterizing decrease in vowel duration over time. However, there was no significant difference in vowel duration before preserved obstruent codas and deleted obstruent codas as well as open syllables (b):

(a)   Vowel duration: $V\cancel{C}_{[son]}* > VC_{[son]}$ and CV

(b)   Vowel duration: $V\cancel{C}_{[obs]}* = VC_{[obs]}$ and CV

     * $\cancel{C}_{[son]}$ and $\cancel{C}_{[obs]}$ refer to coda deletion of sonorant or obstruent, respectively.

These findings are similar to those reported by Ota (2003). Ota compared the duration of vowels preceding a deleted coda to that of the duration of short target vowels in an open syllable. The results showed that, in all three children in his study, the short targeted vowel that preceded a deleted nasal coda was significantly longer than a target short vowel in an open syllable. He claimed that these findings support the hypothesis that the loss of a nasal coda induces the lengthening of the preceding short vowel. As previously mentioned, however, Japanese, unlike IH, is a moraic language distinguishing between light (one mora) and heavy (two moras) syllables, and thus CVL in this case is clearly a case of mora preservation.

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[7] Sonorant consonants are similar to vowels on the sonority scale and thus more likely than obstruents to participate as syllable heads i.e. be syllabic (e.g. English, Yiddish).

It seems, therefore, that vowel duration is longer before sonorant codas than before obstruent codas. However, when the coda is deleted, vowel lengthening occurs only before sonorant codas and not before obstruent codas. These findings raise the following questions: (a) What are the factors that influence CVL to occur only before deleted sonorant codas but not before deleted obstruent codas? (b) Is there a different phonological representation in the child's lexicon for sonorant segments in comparison to obstruent segments? *or* (c) Are these findings a result of auditory deprivation that may affect both: auditory perception and auditory coordination?

Recent research has explained syllable weight using phonetic correlations (Maddieson 1993; Hubbard 1994, 1995; Broselow et al. 1997; Gordon 2002a, 2005). These studies demonstrate a direct connection between phonological weight and a number of phonetic properties, both acoustic and perceptual. Broselow et al. (1997), for example, show a correlation between moraic representation and segment duration. They described different patterns of moraic representation in three languages: (i) The Hindi pattern is characterized by moraic representation for all codas in CVC syllables. Since the coda bears the mora, it does not affect the moraic content of the preceding vowel. (ii) In the Malayalam pattern, the coda has no moraic representation and it shares the mora with the preceding vowel. Finally, (iii) in Levantine, a hybrid language, the coda has a moraic representation only after a short vowel but not after long vowels. Thus, it has a mora in CVC structure but shares the mora with the preceding vowel in $CV\widehat{VC}$ structure. They concluded that the vowel and the coda consonant share a mora in languages with light CVC but not in languages with heavy CVC.

Gordon (2002a) introduced a match between phonological weight and a measure of perceptual energy, i.e. the integration of loudness over time. Gordon (2002a,b) used the term "energy profile" which is affected by the type of the coda, i.e. vowels, sonorant and voiced consonants are considered as high energy codas, while obstruent and voiceless consonants are considered as low energy codas. Thus, he explained that languages that have a greater proportion of high energy codas, i.e. vowels, sonorant and voiced consonants, are more likely to treat CVC as heavy than languages with relatively fewer high energy codas. He proposed an overall energy profile of CVC, which takes into account the proportion of sonorant codas relative to obstruent codas and the proportion of voiced codas relative to voiceless codas within a language. He claimed that these two dimensions serve as the best predictors of phonetic energy and therefore they determine the syllable weight of the language. However, Gordon et al. (2008) applied the energy profile on four languages with different phonological weight and reported an interesting finding: the perceptual energy was only matched with phonological weight in languages with light CVC and not in languages with heavy CVC. Thus, in the two languages with light CVC (i.e. Mongolian and Malayalam in their study) the energy values for CVC were similar to those for CV (i.e. light syllable) and less than the values for CVV (i.e. heavy syllable) in keeping with the light status of CVC.

The difference in syllable weight as a result of the type of the consonant in coda position is also demonstrated in tonal languages. In Lithuanian, for example, all sonorant

segments in coda position are tone-bearing, i.e. take the high tone (H). However, the obstruent segments in coda position are not tone-bearing. In other words, CVC syllable with sonorant codas consists of two moras, while a CV or CVC with obstruent codas consists of a single mora (Kenstowicz 1970).

Following the analyses of Broselow et al. (1997), Gordon (2002a,b), and Gordon et al. (2008) for language acquisition, we assume that the moraic representation of the coda depends on the type of the consonant in the coda position. Since sonorant segments are longer than obstruent segments, they have more acoustic prominence or according to Gordon's profile – 'perceptual energy'. As a result, sonorant consonants bear a mora while obstruents are weightless consonants and therefore have no moraic representation in child phonology. Based on the proposal of Gordon et al. (2008), the obstruent codas behave like an open syllable (CV). We introduce the following hypothesis in Figure 7.
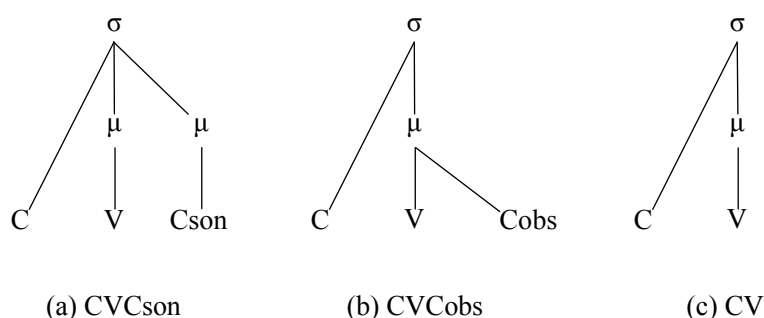

(a) CVCson   (b) CVCobs   (c) CV

Figure 7. The moraic representation of sonorant vs. obstruent codas and open syllable.

As can be seen in figure 7, the sonorant coda has its own mora (a) as in Hindi, while the obstruent coda (b) has no moraic representation, as an open CV syllable (c) but shares the mora with the preceding vowel as in Malayalam. Since only the sonorant coda has a moraic representation, deletion of the coda (as a result of a developmental period, i.e. coda-less stage – see Fikkert 1994; Fee 1995; Grijzenhout and Joppen 1998; Kappa 2002) leads to CVL. In other words, the mora projected by the sonorant, an acoustically prominent consonant, is left disconnected by the segment deletion, and re-associates itself with the preceding vowel, which as a consequence carries two moras. When the coda consists of an obstruent consonant, however, no CVL occurrs as a result of coda deletion because it has short and less prominent acoustical characteristics and thus it shares the mora with the preceding vowel (Figure 8, overleaf).

The above assumption, therefore, raised the following questions: Can we explain the findings of the child with a CI in our study in terms of change in moraic representation over time? Does CVL also occur in the speech of IH-speaking child at the early stages of language acquisition and gradually decrease while the child gains positive

(a) /CVCson/ = *deletion + CVL*
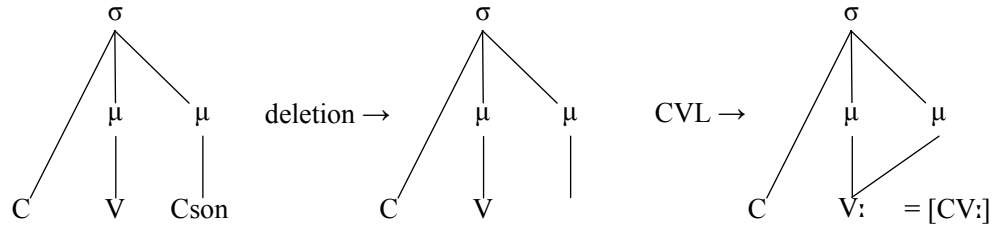
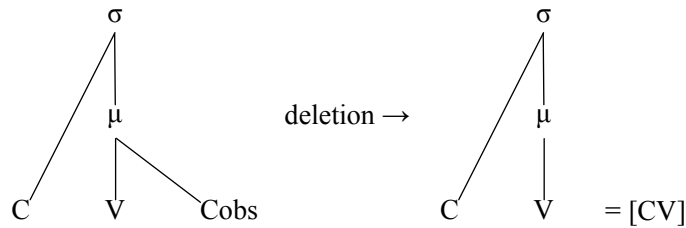

(b) /CVCobs/ = *deletion*

Figure 8: Compensatory vowel lengthening (CVL).

evidence that the mora is not relevant for the phonology of his target language (such as in our case of IH)? These questions, thus, lead us to a further question: Why are there no reports of CVL in the studies of hearing IH-speaking children?

One simple explanation could be that the studies on the prosodic acquisition of IH did not control vowel length, because it is not a distinctive phonemic feature in the language and therefore it does not exist in adult IH. (Both Adam and Ben-David [p.c.] informed us that they did not pay attention to vowel length in their studies, although Ben-David [2001] insisted that she believes that she would have noticed long vowels had they appeared in her data.)[8] Therefore, future research is necessary to examine the speech of hearing IH-speaking children at the initial stage of language acquisition as well as to control vowel length in earlier state, i.e. the babbling stage. The findings of such research may enable us to reach broader conclusions and generalizations concerning CVL in IH.

Since the participant in the study is a child with a CI, we should consider other factors, such as auditory deprivation, that might influence the above results. Nathani et al.

[8] However, in both studies no recording was used during data collection.

(2003) examined final syllable lengthening (FSL) in infant vocalization in order to try to answer the question whether the basis of FSL is biological or learned. The participants of their study consisted of 8 hearing infants (aged 0;3 to 1;0) and 8 deaf infants (aged 0;8 to 4;0), who were matched according to their level of vocal development. They were examined at three levels of prelinguistic vocal development: pre-canonical, canonical, and post-canonical. The findings revealed that both typical hearing and deaf children tend to lengthen final syllables. However, this syllable-lengthening decreases over time in the hearing children only. The researchers suggested that FSL may have biological roots and may, therefore, be motivated by a basic tendency to slow down at the end of the motoric sequences (Oller 1973; Klatt 1976). However, since deaf children lack auditory experience, perhaps they could not use auditory information to manipulate and thereby reduce final syllable durations.

Goffman et al. (2002) claimed that auditory deprivation would have substantial effects on speech motor processes during periods of acquisition, as would the sudden auditory input following implantation. They explained that in deaf children who receive auditory input via CIs, even a short period of auditory deprivation has been found to alter articulatory behavior. When CIs are temporarily turned off, speech production parameters, such as oral-nasal balance (Svirsky et al. 1998), as well as formants and VOT values (Higgins et al. 2001), have been shown to shift from normal range. It seems that auditory input clearly influences speech motor control. In other words, the CVL phenomenon in the speech of our child with a CI might be a result of auditory deprivation, which may affect auditory perception and motor coordination in the initial period after implantation.

Another option is that the CVL does exist in the speech of normally hearing children but does not persist beyond the babbling stage. Thus, one may assume that due to the late onset of sufficient auditory feedback of the child with a CI, there was a long period of transition from babbling to speech. Consequently, sounds and structures characterizing babbling, but not the target language, persisted during the initial stage of speech.

One additional caveat concerning the CDS (child directed speech) during the recording sessions: the data of the child with a CI were collected during therapy. It is often the case that clinicians speak to the child at a slower rate and higher intensity and frequency than that in normal speech, which may result in vowel lengthening. However, it is not very likely that clinical intervention could lead to the phonological conditions of vowel length noted above.

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REFERENCES

Adam, G. 2002. From variable to optimal grammar: Evidence from language acquisition and language change. (Unpublished PhD dissertation, Tel-Aviv University.)

Adam, G. and O. Bat-El. 2007. "Segmental effects on syllable selection: Evidence from Hebrew". In: Gavarró, A. and M.J. Freitas (eds.), *Language acquisition and development: Proceedings of GALA*. Newcastle: Cambridge Scholars Publishing. 1–11.

Adi-Bensaid, L. 2006. The prosodic development of Hebrew-speaking hearing impaired children. (Unpublished PhD dissertation, Tel-Aviv University.)

Adi-Bensaid, L. and O. Bat-El. 2004. "The development of the prosodic word in the speech of a hearing-impaired child with a cochlear implant device". *Journal of Multilingual Communication Disorders* 2. 187–206.

Ben-David, A. 2001. Language acquisition and Phonological theory: Universal and variable processes across children and across languages. (Unpublished PhD dissertation, Tel-Aviv University.) [In Hebrew.]

Bennett, S. 1981. "Vowel formant frequency characteristics of preadolescent males and females". *Journal of the Acoustical Society of America* 67. 231–238.

Bernhardt, B.H. and J.P. Stemberger. 1998. *Handbook of phonological development from the perspective of constraint-based nonlinear phonology*. San Diego: Academic Press.

Boersma, P. and D. Weenink. 2009. Praat. (Computer program.) <http://www.praat.org/>

Bolozky, S. and M. Becker. 2006. Living lexicon of Hebrew nouns. (Ms., University of Massachusetts, Amherst.)

Boothroyd, A. 1991. "Assessment of speech perception capacity in profoundly deaf children". *American Journal of Otology* 12. 67–72.

Broselow, E., S. Chen and M. Huffman. 1997. "Syllable weight: convergence of phonology and phonetics". *Phonology* 14. 47–82.

de Chene, B. and S.R. Anderson. 1979. "Compensatory lengthening". *Language* 55(3). 505–535.

Demuth, K. and E.J. Fee. 1995. Minimal prosodic words in early phonological development. (Ms., Brown University and Dalhousie University.)

Ertmer, D.J. 2001. "Emergence of a vowel system in a young cochlear implant recipient". *Journal of Speech, Language, and Hearing Research* 44. 803–813.

Ertmer, D.J., K.I. Kirk, S.T. Sehgal, A.I. Riley and M.J. Osberger. 1997. "A comparison of vowel production by children with multichannel cochlear implants or tactile aids: Perceptual evidence". *Ear and Hearing* 18. 307–315.

Ertmer, D.J., A. Young, K. Grohne, J.A. Mellon, C. Johnson, K. Corbett and K. Saindon. 2002. "Vocal development in young children with cochlear implants: Profiles and implications for intervention. *Language, Speech, and Hearing Services in Schools* 33. 184–195.

Fee, E.J. 1995. "The phonological system of a specifically language-impaired population". *Clinical Linguistics and Phonetics* 9(3). 189–209.

Fikkert, P. 1994. *On the acquisition of prosodic structure*. The Hague: Holland Academic Graphics.

Geers, A. and C. Brenner. 1994. "Speech perception results: Audition and lipreading enhancement". *Volta Review* 96. 97–108.

Goffman, L., D.J. Ertmer and C. Erdle. 2002. "Changes in speech production in a child with a cochlear implant: Acoustic and kinematic evidence". *Journal of Speech, Language, and Hearing Research* 45. 891–901.

Gordon, M. 2002a. "A phonetically-driven account of syllable weight". *Language* 78. 51–80.

Gordon, M. 2002b. "Weight-by-position adjunction and syllable structure". *Lingua* 112. 901–931.

Gordon, M. 2005. "A perceptually-driven account of onset-sensitive stress". *Natural Language and Linguistic theory* 23. 595–653.

Gordon, M. 2006. *Syllable weight: Phonetics, phonology, typology*. New York: Routledge.

Gordon, M., C. Jany, C. Nash and N. Takara. 2008. "Vowel and consonant sonority and coda weight: A cross-linguistic study". In: Change, C.B. and H.J. Haynie (eds.), *Proceedings of the 26th West Coast Conference on Formal Linguistics*. Somerville, MA: Cascadilla Proceedings Project. 208–216.

Grijzenhout, J. and S. Joppen. 1998. First step in the acquisition of German phonology: A case study. (Ms., Heinrich-Heine University, Düsseldorf.)

Hayes, B. 1986. "Inalterability in CV phonology". *Language* 62. 321–351.

Hayes, B. 1989. "Compensatory lengthening in moraic phonology". *Linguistic Inquiry* 20. 253–306.

Higgins, M.B., E.A. McCleary and L. Schulte. 2001. "Articulatory changes with short-term deactivation of the cochlear implants of two prelingually deafened children". *Ear and Hearing* 22. 29–45.

Hohepa, P. 1967. *A profile generative grammar of Maori*. (Indiana University Publications in Anthropology and Linguistics, Memoir 20.) Baltimore: Waverly Press.

Hubbard, K. 1994. Duration in moraic theory. (Unpublished PhD dissertation, University of California, Berkeley.)

Hubbard, K. 1995. "'Prenasalised consonants' and syllable timing: Evidence from Runyambo and Luganda". *Phonology* 12. 235–256.

Hyman, L. 1985. *A theory of phonological weight*. Dordrecht: Foris.

Kappa, I. 2002. "On the acquisition of syllabic structure in Greek". *Journal of Greek Linguistics* 3. 1–52.

Kehoe, M., and C. Lleó. 2003. "The acquisition of nuclei: A longitudinal analysis of phonological vowel length in three German-speaking children". *Journal of Child Language* 30. 527–556.

Kehoe, M., and C. Stoel-Gammon. 2001. "Development of syllable structure in English speaking children with particular reference to rhymes". *Journal of Child Language* 28. 392–432.

Kenstowicz, M. 1970. "On the notation of vowel length in Lithuanian". *Papers in Linguistics* 3. 73-113.

Kent, R.D. and H.R. Bauer. 1985. "Vocalization of one-year-olds". *Journal of Child Language*, 12. 491–526.

Klatt, D.H. 1976. "Linguistic uses of segmental duration in English: Acoustic and perceptual evidence. *Journal of the Acoustic Society of America* 59(5). 1208–1221.

Ladefoged P. 2001. *A course in phonetics*. Orlando, FL: Harcourt Brace Jovanovich.

Levelt, C. 1994. On the acquisition of place. (Unpublished PhD dissertation, Institute of Generative Linguistics, Leiden.)

Lowenstamm, J. and J. Kaye. 1986. "Compensatory lengthening in Tiberian Hebrew". In: Wetzels L. and E. Sezer (eds.), *Studies in compensatory lengthening*.(Publications in Language Sciences 23.) Dordrecht: Foris. 97–132.

Maddieson, I. 1993. "Splitting the mora". *UCLA Working papers in Phonetics* 83. 9–18.

Miyamoto, R.T., M.J. Osberger, A.M. Robbins, W.A. Myres and K.S. Kessler. 1993. "Prelingually deafened children's performance with the nucleus multichannel cochlear implant". *American Journal of Otology* 14. 437–445.

Most, T., O. Amir and Y. Tobin. 2000. "The Hebrew vowel system: Raw and normalized acoustic data". *Language and Speech* 43. 295–308.

Nathani, S., D.K. Oller and A.B. Cobo-Lewis. 2003. "Final Syllable Lengthening (FSL) in infant vocalizations". *Journal of Child Language* 30. 3–25.

Oller, D.K. 1973. "The effect of position in utterance on speech segment duration in English". *Journal of the Acoustical Society of America* 54. 1235–1247.

Ota, M. 1999. Phonological theory and the acquisition of prosodic structure: Evidence from child Japanese. (Unpublished PhD dissertation, University of Georgetown.)

Ota, M. 2003. *The development of prosodic structure in early words: Continuity, divergence and change.* Amsterdam: Benjamins.

Sezer, E. 1986. "An autosegmental analysis of compensatory lengthening in Turkish". In: Wetzels, L. and E. Sezer (eds.), *Studies in compensatory lengthening.* (Publications in Language Sciences 23.) Dordrecht: Foris. 227–250.

Smit, A.B. 1993. "Phonological errors distributions in the Iowa-Nebraska articulation norms project: Word-initial consonant clusters". *Journal of Speech and Hearing Research* 36. 931–947.

Stemberger, J. 1992a. "A performance constraint on compensatory lengthening in child phonology". *Language and Speech* 35. 207–218.

Stemberger, J. 1992b. "Vocalic underspecification in English language production". *Language* 68(3). 492–524.

Svirsky, M.A., D. Jones, M.J. Osberger and R.T. Miyamoto. 1998. "The effect of auditory feedback on the control of oral-nasal balance by pediatric cochlear implant users". *Ear and Hearing* 19. 385–393.

Tobey, E.A. and A.E. Geers. 1995. "Speech production benefits of cochlear implants". In: Uziel, A.S. and M. Mondain (eds.), *Cochlear implants in children.* Basel: Karger. 146–153.

Tobey, E.A., A.E. Geers and C. Brenner. 1994. "Speech production results: Speech featureacquisition". *Volta Review* 96(5). 109–129.

Tobin, Y. 1997. *Phonology as human behavior: Theoretical implications and clinical applications.* Durham, NC: Duke University Press.

Tobin, Y. 2002. "Phonology as human behavior: Theoretical implications and cognitive and clinical applications". In: Fava, E. (ed.), *Linguistic theory, speech and language pathology, speech therapy.* Amsterdam: Benjamins. 3–22.

Tobin, Y. (ed.) 2009a. *Special theme issue: Phonology as human behavior.* (*Asia Pacific Journal of Speech, Language and Hearing* 12(2).)

Tobin, Y. 2009b. "Modern Hebrew? (B) Contemporary Hebrew? (C) Israeli Hebrew? (D) Israeli?: Choose one of the above. Or: Is the glass half-empty or half-full? Or: Where do you draw the line of demarcation and why?" *Iyunim be Safa ve-Hevra/Israel Studies of Language and Society* 2(1). 137–144.

Trubetzkoy, N. 1939. *Principles of phonology.* (Translated by Christiane A.M. Baltaxe.) Berkeley: University of California Press.

Tye-Murray, N. and K.I. Kirk. 1993. "Vowel and diphthong production by young users of cochlear implants and the relationship between the Phone Level Evaluation and spontaneous speech". *Journal of Speech and Hearing Research* 36. 488–502.

Wetzels, L. 1986. "Phonological timing in Ancient Greek". In: Wetzels, L. and E. Sezer (eds.), *Studies in compensatory lengthening.* (Publications in Language Sciences 23.) Dordrecht: Foris. 279–344.

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