Perception of Suprasegmental Features of Speech by Children With Cochlear Implants and Children With Hearing Aids

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This study assessed perception of suprasegmental features of speech by 30 prelingual children with sensorineural hearing loss. Ten children had cochlear implants (CIs), and 20 children wore hearing aids (HA): 10 with severe hearing loss and 10 with profound hearing loss. Perception of intonation, syllable stress, word emphasis, and word pattern was assessed. Results revealed that the two HA groups significantly outperformed the CI group in perceiving both intonation and stress. Within each group, word pattern was perceived best, and then intonation and emphasis, with syllable stress perceived poorest. No significant correlation emerged between age at implantation and perception of the various suprasegmental features, possibly due to participants' relatively late age at implantation. Results indicated that CI use did not show an advantage over HA use in the perception of suprasegmental features of speech. Future research should continue to explore variables that might improve this perception.

Speech comprised segmental features relating to the characteristics of the individual phonemes (vowels and consonants) and suprasegmental features such as intonation, stress, and emphasis, which are carried along the syllable, the utterance, or the sentence (Snow, 2001). The suprasegmental features of speech play a very important role in the process of understanding speech. They enable the listener to interpret the speaker's communicative intentions, such as differentiating a question from a statement or differentiating between a noun and a verb, as in the following case of syllable stress: 'object versus ob'ject. Thus, suprasegmental features are essential to the communication process (Borden, Harris, & Raphael, 1994).

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Perception of suprasegmental features is accomplished through perception of the time–energy envelope of the speech signal and/or its fundamental frequency information. Listeners perceive a sentence's intonation mainly through the changes in fundamental frequency along the sentence. Along these changes, time and intensity aspects also change, serving as acoustic cues in the perception process (Cohen-Licht & Most, 2000; Grant, 1987; Most, 1985). The perception of a sentence's syllable stress or word emphasis is also accomplished through the perception of the time–energy envelope of the speech signal and/or its fundamental frequency information. The stressed syllable (as in 'rebel vs. re'bel) or the emphasized word (as in Tom wants to drink vs. Tom wants to drink) is characterized by a higher fundamental frequency, longer duration, and greater amplitude in comparison to the same but unstressed syllable or unemphasized word (Borden et al., 1994). By using synthetic stimuli and controlling the changes of each of these parameters, researchers found that each of these comprised an effective perception cue (Fry, 1955; Isenberg & Gay, 1978).

Many individuals with severe or profound hearing loss have residual hearing in the lower frequency region. Previous research reported that, with hearing aids (HA), some of them can detect and discriminate the time–energy envelope of the speech signal, and others can also detect and discriminate fundamental frequency information (Engen, Engen,

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Clarkson, & Blackwell, 1983; Erber, 1979). Inasmuch as the suprasegmental features are cued by duration, amplitude, and fundamental frequency information, various researchers have claimed that such features should be available to many individuals with hearing loss (e.g., Boothroyd, 1984). Some previous research reported success in perceiving intonation (Most & Frank, 1991) and stress (Most, 2000) when using tasks with empirically evidenced validity and interventions that specifically exposed these auditory cues to the children. Yet, other researchers reported difficulties in perceiving stress (Jackson & Kelly, 1986) or intonation (Stark & Levitt, 1974). Moore (1998) claimed that many individuals with hearing loss have deficits in frequency and temporal resolution. Inasmuch as perception of suprasegmental features relies on these abilities, many individuals with severe or profound hearing loss experience difficulties in perceiving them.

For individuals with sensorineural hearing loss, the perception of intonation is considered as the most difficult of the suprasegmental features because it relies mainly on the perception of changes in fundamental frequency, which are not accessible to many individuals. Perception of the other features, on the other hand, relies mainly on the time–energy envelope, which is more accessible (Borden et al., 1994). Children with severe and profound hearing loss had more difficulties in the perception of yes/no questions, which are cued by a rising intonation contour, than in the perception of statements, which are cued by a falling intonation contour (Most & Frank, 1991). Also in an earlier study, Most (1985) reported successful perception of intonation even in children with profound hearing loss, provided they had received early and intensive intervention.

With regards to the perception of stress, some researchers (Jackson & Kelly, 1986; Osberger & McGarr, 1982) reported that individuals with hearing loss often experience difficulties in perceiving the stress pattern. Rubin-Spitz and McGarr (1986) found that participants with severe and profound hearing loss succeeded in perceiving the stress pattern only in those stimuli where the stressed and unstressed syllables differed in amplitude. In contrast, Most (2000) reported an 80.3% success rate in perceiving syllable stress among Hebrew speaking participants with severe and profound hearing loss. She claimed that inasmuch as the perception of syllable stress relies mainly on the time–energy envelope of the speech signal, this feature should be relatively easy to perceive. Most attributed the participants' success in perceiving the stress pattern to the utilization of an appropriate and natural task, comprising meaningful sentences containing minimal pairs of target words that differed in their stress pattern.

The perception of word pattern (the number of syllables in a word) is considered to be very basic and accessible to most individuals, even those with profound hearing loss (Boothroyd, 1984; Geers & Moog, 1989). Using the Hebrew version of the Early Speech Perception battery (Geers & Moog, 1989), Kishon-Rabin et al. (2000) showed that children with profound hearing loss (poorer than 100 dBHL) had difficulties perceiving one-syllable words; however, they were able to perceive the word pattern.

In summary, studies on the perception of suprasegmental features by children using HA demonstrated that although suprasegmental features are easier to perceive than segmental ones (Boothroyd, 1984), many individuals with severe and profound hearing loss do experience difficulties in perceiving the former. Studies revealed that word pattern was perceived by most participants, whereas intonation, stress, and emphasis were reported as difficult to perceive by many individuals with severe to profound hearing loss (e.g., Gold, 1987).

Cochlear implant (CI) technology has opened up new rehabilitation options for spoken language use among individuals with severe and profound hearing loss. Many speech features that were not audible via the acoustic amplification of HA became audible via the electrical stimulation of the CI, thus improving the ability to perceive speech (Waltzman & Hochberg, 1990). Many studies that compared the perception of speech by children and adults using CI to those with similar hearing loss using HA showed the advantage of the CI over the hearing aid (Boothroyd & Eran, 1994; Blamey et al., 2001). However, most of these studies evaluated the perception of segmental features.

Much less research attention, however, has been given to the perception of suprasegmental features. Only a few studies examined the perception of suprasegmental features by participants with CI, and among these, some were conducted several years ago (e.g., Carney, Kienle, & Miyamoto, 1990; Waltzman & Hochberg, 1990), a possibly important factor when considering technological developments and modifications in CIs. For example, Carney et al. evaluated the perception of suprasegmental features by participants with a single-channel CI. Intonation was perceived best and syllable stress least well. Waltzman and Hochberg (1990) found that children with Nucleus 22-channel CI as well as children with HA performed well in perceiving word emphasis and pitch changes. Boothroyd and Eran (1994) reported that children who used the Nucleus CI did not significantly differ from children with HA in their perception of syllable number, but children with HA did perform better at perceiving intonation. The children in that study revealed hearing loss ranging between 82 and 117 dB (M = 99 dBHL).

Interestingly, research on intonation perception by implanted participants with older processors showed better performance than by those who used more advanced ones. Based on their results for participants with the Clarion CI with CIS speech processing strategy, Green, Faulkner, and Rosen (2004) claimed that the perception of pitch by today's CI utilizes temporal rather than spectral information. Also, O'Halpin, Falkoner, Rosen, and Viani (2006) suggested that their study participants who used CI Nucleus 24 (with ACE and SPEAK) did not rely on changes in fundamental frequency when perceiving word emphasis following a presentation of synthetic speech with controlled changes in each of the acoustic parameters (amplitude, duration, and fundamental frequency).

In light of the shortage of research on suprasegmental features, despite their importance for successful communication, this study aimed to assess the perception of suprasegmental features of speech by children with CI in comparison to that of children wearing HA, at different levels of hearing loss.

Method

Participants

Thirty children aged 8–15 years with prelingual bilateral sensorineural hearing loss participated in the study. The CI group comprised 10 children with profound hearing loss (>90 dBHL) who used CI. The HAS group comprised 10 children with severe hearing loss (M = 77 dBHL, standard deviation [SD] = 4.96) who used HA. The HAP group comprised 10 children with profound hearing loss (M = 99 dBHL, SD = 6.73) who used HA. Degree of hearing loss for children in the HAS and HAP groups was determined according to the pure tone average of 500 Hz, 1 KHz, and 2 KHz in the better ear. Hearing loss in the HAS and HAP groups was detected at a young age (between 1 and 3 years old). Children were fitted with digital HA from that time, using a DSL fitting procedure. See Appendices A and B for residual hearing at low frequencies among children in the two HAP and HAS subgroups, respectively.

Participants in the CI group used Nucleus 24 with ACE processing strategy (e.g., Pasanisi et al., 2002). Their age of implantation ranged from 3:6 to 12:4 years (M = 7:11, SD = 3.14). Duration of CI use ranged from 1 to 8 years (M = 4:2, SD = 2.32). All implantees had well-established maps with dynamic range (M level–T level) between 40 and 60 current levels.

All 30 children had hearing parents, and spoken Hebrew was their native language. They used spoken language as their main mode of communication and were fully integrated, individually, in regular classes with hearing children. None of the participants had additional handicaps. They all received speech and language therapy from the time of hearing loss detection. The participants had no reading difficulties, according to their teachers' reports.

Stimulus Materials

Perception of word pattern, syllable stress, sentence intonation, and word emphasis was evaluated via four closed-format tests where recorded speech materials were presented to the children for identification among printed alternatives.

Word pattern. The pattern perception test included 12 items, each with three words of differing syllable number. Each of the 36 Hebrew words (12 items × 3 words) was printed on a separate card. Each item contained a one-syllable, a two-syllable, and a three-syllable word. To avoid confusion, the number of syllables was determined according to both the dictionary and the speech envelope, considering that the two could conflict in their criteria for number of syllables, as in the word "lemon," which is two syllables by dictionary but one syllable by speech envelope (Erber, 1979). The speech envelope was examined using IBM Speech-viewer III software, which provides both visual and auditory analyses of speech attributes such as pitch, loudness, and timing. In each item, all three words began with a similar syllable. For example: *gir* (chalk), *gibor* (hero), and *giborim* (heroes) or *bat* (daughter), *batim* (houses), and *batata* (sweet potato). For the word pattern test, the total of 36 words was divided into two lists of 18 words each. Children were asked to identify each verbally presented, recorded word out of 18 printed alternative words. A correct response was considered when a word in the same category (i.e., one syllable, two syllable, or three syllable) was chosen.

Intonation. The intonation subtest from the Hebrew Speech Pattern Contrasts (HeSPAC) (Kishon-Rabin, Eran, & Boothroyd, 1990), which was based on Boothroyd's (1984) SPAC in English, assessed the ability to discriminate between a statement and a yes/no question. Two lists totaling 48 sentences were used. Each list contained 12 sentences, each comprising familiar words that could have two possible intonation curves—a statement or a question (i.e., totaling 24 items in each list). Each sentence was printed twice: once as a statement with a period at the end, for example, *cham po.* (It's hot here.), and once as a question with a question mark at the end, for example, *cham po?* (Is it hot here?). For the intonation test, children were asked to listen to each audio-recorded sentence and report whether it was a statement or a question.

Syllable stress. Word syllable stress was assessed through the use of 12 bisyllabic, meaningful, minimal, familiar pairs differing in their stress pattern; for example, *'bira* (beer) and *bi'ra* (capital). The original test (Most, 2000) included 10 minimal pairs, and 2 additional pairs were included for the purpose of this study, for a total of 24 words. Each word was printed within a meaningful sentence; for example, *ani shote 'bira* (I drink beer) and *Jerusalem ir bi'ra* (Jerusalem is the capital). All 12 sentence pairs were printed on the same sheet of paper. For the syllable stress test, children were asked to listen to each of the recorded words, presented in a random order, and to identify which sentence contained that word with that stress pattern out of the pair of sentences.

Word emphasis. Perception of word emphasis in a sentence was evaluated using two lists of this subtest from the HeSPAC (Kishon-Rabin et al., 1990). Each list included 12 sentences containing three one-syllable words. Each of the 12 sentences was recorded three times, once with the first word emphasized, once with the second word emphasized, and once with the third word emphasized, thus totaling 36 sentences in each of the two lists. Each of the 12 sentences was printed three times, with the first, second, or last word emphasized through the use of bold print. For example, ***ten** li gir*, *ten **li** gir*, and *ten li **gir*** (Give me a piece of chalk). For the word emphasis test, children were asked to listen to each recorded sentence and identify the appropriate printed sentence out of the three possible alternatives.

Procedure

All the speech materials were first recorded by a native Hebrew-speaking woman with clear voice and articulation using Sony's Sound Forge 7 software. To maintain consistent intensity throughout, the recordings were normalized. The stressed syllables and the emphasized words were normalized separately in order to keep the inherent intensity differences. The difference between the intensity level of these parts and the rest of the sentence was retained, as was measured in the original recording.

To achieve validity, all the recorded materials were introduced in a pilot study to five children with normal hearing, aged 8:8–15:3 (M = 12, SD = 2.42). The obtained mean correct identification scores for the four tests ranged between 95% and 100%.

In this study, each participant was evaluated alone in the same quiet room using his/her own well-functioning and optimally fitted sensory aids (CI or HA). Sensory aids' functioning was checked by the examiner using a status clip for the hearing aid or a signal checker for the CI, as well as Ling's (1976) six sounds test.

The test materials were presented at normal conversational level (72 dBSPL) at the child's seat through the use of a JVC CD Portable RC-X501 tape recorder. Before each test, the printed materials were first introduced to the child to ascertain familiarity with the words. The examiner explained each task and introduced a few practice items (not included in the test) to ensure participants' understanding. The child was instructed that each of the stimulus words/sentences may appear more than once, to ensure that children continue listening for that stimulus even after it was presented and thus eliminate attempts to guess according to a process of elimination.

In each of the four tests, the order of presentation of the test stimuli was randomized. The order of presentation of the different tests was randomized among the participants.

Results

Each child received a score for the percent of correct responses regarding each of the four suprasegmental features: word pattern, intonation, stress, and emphasis. Inasmuch as closed-set materials were used, the scores were corrected for guessing using Boothroyd's (1988) formula, which accounts for the number of possible alternatives as follows:

$$\text{Corrected score} = \left(\frac{\text{uncorrected score} - \%\ \text{probability for correct answer}}{\%\ \text{probability for error}}\right) \times 100.$$

The mean scores of each of the three groups on the different speech perception tests were compared. Table 1 presents the mean scores (in percentages) and the *SDs* of the three groups on the four tests. Multivariate analysis of variance revealed significant differences among the groups, $F(8, 50) = 4.73$, $p < .001$. One-way analyses of variance (ANOVAs) on each of the tests revealed significant differences between the groups on the perception of syllable stress, $F(1, 27) = 12.51$, $p < .001$, and on the perception of intonation, $F(1, 27) = 14.22$, $p < .001$. Bonferroni tests, conducted to examine the source of these differences, revealed that in both the intonation and stress tests, the CI group performed significantly poorer than the HAS and HAP groups ($p < .05$). The performance of the two hearing aid groups did not differ significantly from each other ($p > .05$). No significant differences emerged among the three groups in the perception of word pattern or in the perception of emphasis ($p > .05$).

To examine differences between the four test scores within each of the groups, two-way ANOVA with repeated measures was conducted. A significant interaction between group and test emerged, $F(6, 81) = 9.62$, $p < .001$. Bonferroni tests within each group, conducted to examine the source of these differences, revealed that within the CI group the word pattern was perceived significantly better than all the other tests ($p < .05$). Word emphasis was perceived significantly better than stress and intonation ($p < .05$). Stress was significantly more difficult to perceive than the other three features ($p < .05$).

Among the HAP group, the word pattern was perceived significantly better than the stress, and both emphasis and intonation were perceived significantly better than the stress ($p < .05$). In the HAS group, the word pattern was perceived significantly better than the stress ($p < .05$), but no other significant

Table 1 Mean scores (in percentages) and *SDs* on the four tests, by group

	CI (n = 10)		Hearing aid—profound loss (n = 10)		Hearing aid—severe loss (n = 10)			
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*	$F(1, 27)$	Effect size
Pattern	97.05	4.38	94.76	6.34	99.11	1.42	2.31	0.15
Stress	20.83	27.56	47.5	26.07	73.33	14.59	12.51***	0.48
Emphasis	72.92	15.8	82.08	14.09	88.33	11.49	3.10	0.19
Intonation	42.5	27.55	80.82	18.85	89.99	14.98	14.22***	0.51

***$p < .001$.

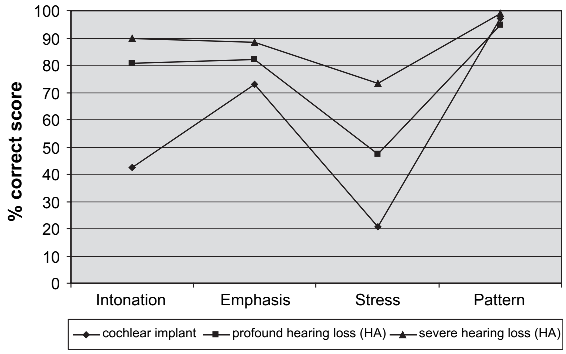

Figure 1 Performance on the four tests within each group.

differences emerged among the tests in this group ($p > .05$). Figure 1 demonstrates the performance of each group on the four different tests.

Error Types

We examined children's types of errors on the stress, intonation, and emphasis tests, but not for the word pattern test because its scores were very high for all groups.

In the stress test, there were two possible errors: perceiving a word with initial stress as one with final stress and perceiving a final stress as an initial one. One-way ANOVAs revealed a significant difference between the groups for each error type, $F(2, 27) = 4.26$, $p < .05$. Bonferroni tests for each of these two error types revealed a significant difference between the CI group ($M = 51.43$, $SD = 15.10$) and the HAS group ($M = 21.16$, $SD = 25.80$) in substituting final stress for initial ($p > .05$). Also, there was a tendency toward a significant difference for this kind of substitution between the HAP group ($M = 49.30$, $SD = 33.34$) and the HAS group ($p = .06$). No significant difference emerged between the CI and HAP groups for this error type ($p > .05$). There were no significant differences between the groups in the percentage that erroneously perceived a final stress as an initial one ($p > .05$).

A two-way ANOVA with repeated measures revealed no significant difference in the percent of error type ($p > .05$). There was a significant interaction between error type (%) and group, $F(2, 27) = 4.27$, $p < .05$. Bonferroni tests revealed that the percent of errors perceiving final stress as initial was higher (78.84%) than the percent of errors perceiving initial stress as final (21.16%) in the HAS group ($p < .05$). In both the CI and the HAP groups, no significant differences emerged in the percentages of the two error types ($p > .05$).

For the emphasis test, there were three categorical alternatives: substitution of initial emphasis for medial or final emphasis (HAS: $M = 49.70$, $SD = 35.77$; HAP: $M = 28.76$, $SD = 20.23$; CI: $M = 32.40$, $SD = 15.51$), substitution of medial emphasis for initial or final emphasis (HAS: $M = 26.85$, $SD = 25.95$; HAP: $M = 37.20$, $SD = 33.70$; CI: $M = 44.5$, $SD = 13.22$), and substitution of final emphasis for initial or medial emphasis (HAS: $M = 23.45$, $SD = 33.65$; HAP: $M = 34.03$, $SD = 20.35$; CI: $M = 23.1$, $SD = 18.33$). To evaluate differences in percentages of errors, a two-way ANOVA with repeated measures was conducted. This analysis revealed no significant differences in the percent of error types as well as no significant interaction between error type and group ($p > .05$).

For the intonation test, there were two possible errors: perception of a yes/no question as a statement (HAS: $M = 86.90$, $SD = 21.38$; HAP: $M = 80.10$, $SD = 28.20$; CI: $M = 60.40$, $SD = 17.76$) and perception of a statement as a question (HAS: $M = 13.10$, $SD = 21.38$; HAP: $M = 19.90$, $SD = 28.20$; CI: $M = 39.60$, $SD = 17.76$). One-way ANOVAs revealed no significant differences between the groups for either type of error ($p > .05$). A two-way ANOVA with repeated measures revealed a significant difference in the error type, $F(1, 23) = 30.6$, $p < .001$. Substitution of a statement for a question was significantly higher (75.81%) than substitution of a question for a statement (24.19%). No significant differences emerged between the groups, and no significant interaction emerged between error type and group ($p > .05$).

Within-Group Correlations

The relationships among the different tests within each group were examined. Within the CI group, Pearson product–moment tests revealed significant correlations between intonation and stress perception ($r = .66, p < .05$) and between intonation and emphasis ($r = .83, p < .01$) but insignificant correlations between word pattern and the other tests ($p > .05$). Within the HAP group, significant correlations emerged between emphasis and word pattern ($r = .67, p < .05$), between intonation and syllable stress ($r = .68, p < .05$), and between intonation and emphasis ($r = .87, p < .05$). Within the HAS group, significant correlations ($p < .05$) emerged between word pattern and all three other tests: with stress ($r = .71$), with emphasis ($r = .84$), and with intonation ($r = .82$). Also, a significant correlation appeared between stress and intonation ($r = .79, p < .05$).

Demographic Variables

For CI users, no significant correlations emerged between age at implantation and performance on any of the tests. Also, no significant correlation emerged between duration of implant use and suprasegmental perception performance ($p > .05$).

For the two hearing aid groups, examination of the correlations between degree of hearing loss and suprasegmental perception yielded significant negative correlations only for the HAP group. In this group ($n = 10$), greater degree of hearing loss correlated with lower test performance for pattern ($r = -.67, p < .05$), stress ($r = -.29, p < .05$), emphasis ($r = -.79, p < .01$), and intonation ($r = -.66, p < .05$).

Discussion

Usage of the CI has been shown to enable more audibility to the speech signal and consequently better perception of speech by children who use CI in comparison to those with a similar degree of hearing loss who use HA (Blamey et al., 2001; Meyer, Svirsky, Kirk, & Miyamoto, 1998). Most such research, however, reported on the perception of the segmental features of speech. This study aimed to examine the perception of speech's suprasegmental features by children with hearing loss, while comparing children with CI to children with severe and profound hearing loss who use HA. In contrast to previously reported results on the contribution of the CI to the perception of speech in general, the current findings indicated that the CI group's performance in the perception of suprasegmental features of speech did not surpass that of either hearing aid group. Thus, the present results do not reflect an advantage of children with CI over children using HA. Indeed, for two of the four tests (stress and intonation), the CI group performed significantly poorer than the two hearing aid groups.

The good performance of the two hearing aid groups may be explained by the fact that the changes in fundamental frequency as well as the speech envelope, which serve as cues for the listener in perceiving suprasegmental features (Borden et al., 1994), are transmitted through the hearing aid and therefore are audible to individuals with HA who have severe and even profound hearing loss (Boothroyd, 1982; Erber, 1979; Most & Frank, 1991). This ability was reported earlier for the perception of different features, such as intonation (Most, 1985; Most & Frank, 1991) and stress (Most, 2000).

The finding that the CI group did not succeed in perceiving these features or in surpassing those with similar degrees of hearing loss who wore HA may find a possible explanation in that the CI does not provide sufficient information to the listener regarding these suprasegmental features of speech. These features are perceived based on low frequency and temporal information and, as Kong, Stickney, and Zeng (2005) reported, CI listeners exhibit poor pitch perception due to their limited spectral resolution, especially the inaccurate encoding of low-frequency information. These researchers reported that in current CIs, the low-frequency information is neither appropriately represented by the place of stimulation nor by the temporal fine structure of the neural firing pattern. Thus, the CI does not provide adequate information in the low-frequency range. The relatively shallow insertion depth of present electrode arrays severely limits the transfer of low-frequency spectral information. The average insertion depth for the Nucleus implant was estimated to be 20 mm (Ketten et al., 1998), which corresponds to the acoustic frequency lower limit of about 1000 Hz (Greenwood, 1990). Even with the latest electrode designs of all the different CIs, which are intended to provide a deeper insertion of up to 30 mm, there is still no guarantee that low-frequency neurons can be stimulated due to both reduced nerve survival in individuals with hearing loss and nontonotopic distribution of low-frequency neurons in the cochlea (Linthicum, Fayad, Otto, Galey, & House, 1991; Nadol, Young, & Glynn, 1989). In addition, low-frequency temporal information is not appropriately encoded in current speech processing strategies (Kong et al., 2005). Thus, it is possible that the participants in this study did not receive the necessary information regarding temporal and spectral information in the low-frequency range.

As mentioned above, HA, in contrast, enable low-frequency spectral information (Kong et al., 2005). Also Henry and Turner (2003) reported that the acoustic stimulation provided by a hearing aid might provide the user access to finer spectral and temporal pitch cues in the speech signal that are not resolved well by CIs. Thus, it would be of interest in future research to examine the performance of individuals with CI versus individuals with both CI and a hearing aid in their perception of suprasegmental features.

Another important factor that likely affected the CI group's performance was age at implantation. The current sample of children with CIs comprised relatively "late" implantees (8 of the 10 children were implanted after 6 years of age). Previous reports on children with CI showed the central role of age at implantation, where earlier age at implantation revealed a strong positive effect on the child's speech, language, and hearing performance (Dowell et al., 2002; Harrison, Gordon, & Mount, 2005). Harrison et al. compared the perception of words and sentences by children who were implanted between the ages of 2 and 13 years, studying children longitudinally up to 8 years after implantation. The results showed that those who were implanted between the ages of 2 and 3 performed significantly better than those who were implanted later. Also, after a long duration of CI use, the late implantees did not perform as well as the "early" implantees.

Thus, the relatively late implantation after age 6 among most of the present participants (8 of 10) may have had a crucial effect on their performance. The lack of a significant correlation between age at implantation and performance on the different tests supports this notion. As a result of this late age of implantation, the present data should be taken with caution because it is difficult to distinguish between the device's possible technological restrictions and the possible limitations resulting from the late age at implantation (e.g., due to reduced learning time, less exposure during crucial young ages). However, the fact that the CI participants were able to perceive at least some suprasegmental features suggests that the data do have sufficient merit. Future research should assess children who were implanted at a younger age and compare their results to those of this study.

Another explanation for the low performance of the CI group may be that the auditory performance of the participants did not represent their auditory potential. As Boothroyd (1982) reported, auditory performance is a function of both auditory capacity and learning opportunity. Poor auditory performance can result from either poor auditory capacity or inadequate learning opportunity. Therefore, a child with excellent auditory capacity may underachieve because of poor learning opportunities. Although all the participants in the study received speech and language therapy, the emphasis in their auditory training was on the perception of the segmental features and not so much on the suprasegmental features, based on the clinicians' reports.

Klieve and Jeanes (2001) reported that children with CI who received specific training in the perception of suprasegmental features, with and without linguistic context, improved in their perception. This improvement was even evident 10 weeks after the end of the intervention. Future research should assess the perception of suprasegmental features before and after intervention programs. It may also be interesting to intervene with production tasks as well as perception tasks and to examine the relations between perception and production of these speech features. Previous research reported a mutual relationship between perception and production of speech. In other words, improved perception skills may contribute to better production skills (Most & Frank, 1994), and training of production skills may lead to an improvement in perception (Novelli-Olmstead & Ling, 1984).

It should be noted that all our participants used the Nucleus 24 with ACE processing strategy in order to control for the type of implant and processing strategy. However, implants vary in their components, such as number of electrodes or speech coding strategy; hence, other CIs and/or processing strategies could possibly have yielded different results, calling for further research.

Studies on perception of segmental features revealed differences in auditory perception (Psarros et al., 2002; Pasanisi et al., 2002) and subjective feelings (Keifer, Hohl, Stürsebecher, Pfennigdorff, & Gstöettner, 2001) of people who used different coding strategies. Fu, Hsu, and Horng (2004) studied the identification of tone among Chinese individuals with different CIs and showed that the use of the ACE and the CIS coding strategies, in comparison to the SPEAK strategy, resulted in better tone identification. Kong et al. (2005) studied the identification of melodies in a pilot study on a small number of people who used new CIs from all the different companies: Cochlear, Med-El, and Advance Bionics. These authors reported significant differences in participants' performance and suggested that research should continue to search for the source of these differences. Thus, the effect of CI type as well as coding strategy on the perception of suprasegmental features should be further examined in future research.

Another issue examined in the current study was the hierarchy in the perception of the different characteristics within each group. Previous research on hearing aid users reported that pattern perception was easiest to perceive because it is based mainly on the speech envelope (duration and amplitude changes), whereas intonation was the most difficult because it is based mainly on the changes in the fundamental frequency along the utterance. Stress and emphasis lie in between (Gold, 1987). The present results partly supported these previous findings.

The pattern of the word, that is, its number of syllables, was the easiest to perceive by participants of all three groups who obtained high scores. As mentioned, this is a very basic skill, and even people with profound hearing loss may succeed in such tasks (Geers & Moog, 1989; Kishon-Rabin et al., 2000). Next in the hierarchy were emphasis and intonation, and the most difficult was perception of word stress.

The perception of word emphasis by CI users was previously reported by O'Halpin et al. (2006). These authors reported that although their participants had difficulties in differentiating between frequencies, most of them succeeded in the perception of word emphasis in a sentence. They suggested that the participants relied on the intensity and duration cues only.

Interestingly, in contrast to hearing aid users, the better perception of intonation in comparison to syllable stress by CI users was already reported (Carney et al., 1990). These authors, however, examined the perception of a small group of CI users (Nucleus 24) by reading sentences aloud rather than through the use of recorded speech stimuli. This study offered the advantage of more controlled intensity and consistency regarding the stimuli level of presentation.

Also, recall that previously reported results were on English speaking participants, whereas this study was conducted on Hebrew speakers. Differences in the perception hierarchy between this study and previous ones, that is, stress emerging as the most difficult feature to perceive, may perhaps result from linguistic features. In English, the trochaic stress pattern is very common, whereas in Hebrew both the iambic and the trochaic stress are common (Adi-Bensaid & Bat-El, 2004). Possibly, the difference in stress pattern between the languages could have affected the current outcomes, calling for more detailed future study designs regarding this issue.

Another explanation for the lower performance on the syllable stress test in comparison to the other tests lies in how this feature was presented. First, in listening to the syllable stress, the listener heard just a word, whereas for the other features—intonation and emphasis—the listener heard a longer stimulus, that is, a full sentence. Also, the syllable stress test required a different and perhaps more demanding task from the listener. The participant was asked to listen to the word and then to choose the related sentence that contained that word. In other words, the listener had to listen to the meaning and not to the form. This specific task was used because previous research showed its usefulness and validity (Most, 2000). In the other tests, tasks were simpler. In the intonation test, the listener heard a whole sentence and had to decide whether it was a statement or a question. In the emphasis test, the listener heard a whole specific sentence (with one emphasized word) and had to choose that sentence out of three possible alternatives. Thus, for these features, the listener only had to follow the acoustic changes along the sentence. Although, as mentioned, the syllable stress assessment task was reported as more valid than previously used measures in which the listener was required to listen to the word and choose the related written word out of a minimal pair differing in their stress pattern, it is possible that the current stress assessment task was more demanding than the other tasks in the present research.

We wanted to examine whether a certain type of error was more frequent in each of the tests. Specifically, we wished to determine if participants would substitute more initial syllable stress or vice versa, would substitute a question more than a statement, or would substitute initial emphasis more than a medial or a final one. Results showed that for the syllable stress test, no significant differences appeared between the error types for either the CI or HAP groups. In the HAS group, however, children substituted final stress (78.84%) more than initial stress (21.16%). It should be recalled that in general this group made fewer errors than the other two groups. When there were errors, however, they were made as mentioned above. This was quite surprising inasmuch as the frequency of the final stress in two-syllable words is higher than the initial stress. Nevertheless, as Carney et al. (1990) reported, the trochaic stress pattern is easier to perceive and perhaps affected the results.

In the emphasis test, no significant differences emerged in substitution errors for initial, medial, or final emphasis, in any of the groups. Thus, even if the acoustic cues for the perception of word emphasis changed as a function of the emphasized word's position in the sentence (Weiss, Carney, & Leonard, 1985), this did not affect success in perceiving it in the present research.

Regarding intonation perception, all the groups succeeded better in the perception of statements than in the perception of yes/no questions. These results supported previous reports on individuals with HA (Most & Frank, 1991).

In summary, the CI technology opened up new options in the rehabilitation of many individuals with severe and profound hearing loss by enabling a better perception of spoken language. However, it seems that the present CIs are not sufficient in providing acoustic information on the suprasegmental features of speech, which are essential for intelligible communication. It should be noted, though, that the current results should be treated with caution due to the small sample. Future research should continue to examine the different variables with regard to the sensory aid itself, such as the speech processing strategy, and the individual factors such as age at implantation or type of intervention, with the aim of improving perception of suprasegmental speech features through the use of CI.

Appendix A Pure Tone (PT) and Pure Tone Average (PTA) Data on the Subgroup of Children With HA and Profound Hearing Loss ($n = 10$)

Child	PT—right				PTA—right	PT—left				PTA—left
	500	1000	2000	4000		500	1000	2000	4000	
1	100	110	100	90	100.00	110	110	110	115	111.25
2	100	NR	NR	NR		100	100	100	95	98.75
3	85	100	110	115	102.50	85	90	110	120	101.25
4	100	115	120	110	111.25	95	110	115	120	110.00
5	100	105	115	115	108.75	95	110	115	120	110.00
6	90	100	100	110	97.50	95	105	100	105	101.25
7	70	90	100	105	91.25	75	100	100	105	95.00
8	105	105	95	85	97.50	85	95	95	95	92.50
9	90	110	110	115	106.25	100	95	100	105	100.00
10	70	80	105	105	90.00	105	110	105	110	107.50

Appendix B Pure Tone (PT) and Pure Tone Average (PTA) Data on the Subgroup of Children With HA and Severe Hearing Loss ($n = 10$)

	PT—right					PT—left				
Child	500	1000	2000	4000	PTA—right	500	1000	2000	4000	PTA—left
1	55	70	70	85	70.00	50	85	80	115	82.50
2	65	70	95	105	83.75	55	70	80	95	75.00
3	95	95	90	90	92.50	70	85	85	80	80.00
4	55	75	90	100	80.00	50	80	90	NR	
5	55	80	85	70	72.50	55	75	85	80	73.75
6	70	80	95	115	90.00	55	60	65	100	70.00
7	65	85	85	80	78.75	85	90	85	80	82.50
8	70	85	95	85	83.75	85	85	85	80	83.75
9	65	80	80	90	78.75	80	95	90	90	88.75
10	85	80	85	80	82.50	85	85	95	100	91.25

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