

Aided Perception of /s/ and /z/ by Hearing-Impaired Children

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Objective: The overall goal of this study was to determine the accuracy with which hearing-impaired children can detect the inflectional morphemes /s/ and /z/ when listening to speech through hearing aids.

Design: In the first part of the study a perceptual test was developed with equal numbers of singular and plural nouns spoken by both a male and female talker. Thirty-six normal-hearing children (3 to 5 yr) were tested to determine the age at which children could perform this test without difficulty. In the second part of the study, 40 children with bilateral sensorineural hearing losses (5 to 13 yr) were tested while wearing personal hearing aids. Stimuli were presented in the sound field at 65 dB SPL.

Results: For the normal-hearing children, mean performance increased and inter-subject variability decreased through age 5 yr 3 mo when performance reached $\geq 90\%$ for all children. No significant talker or form (plural versus singular) effects were noted for this group. For the hearing-impaired children, performance varied considerably across all ages. For these subjects, significant effects of talker and form were observed. Specifically, plural test items spoken by the female talker showed the highest error rate.

Conclusions: In general, mid-frequency audibility (2 to 4 kHz) appeared to be most important for perception of the fricative noise for the male talker while a somewhat wider frequency range (2 to 8 kHz) was important for the female talker.

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Although the speech, language, and academic characteristics of children with severe-to-profound sensorineural hearing losses have been studied extensively, fewer studies have been conducted with children who have mild-to-moderately severe hearing losses. The lack of focus on the performance of these children may be explained, in part, by the fact that their speech and language problems are likely to be subtle compared to children with greater hearing losses and thus, they may not be referred for comprehensive evaluations. The studies that have been conducted suggest that even mild hearing loss can compromise communication abilities, academic performance, and psychosocial behavior (Bess, Dodd-Murphy, & Parker, 1998; Davis,

Elfenbein, Schum, & Bentler, 1986; Davis, Shepard, Stelmachowicz, & Gorga, 1981; Elfenbein, Hardin-Jones, & Davis, 1994; Markides, 1970, 1983).

Although Elfenbein et al. (1994) reported that the speech of children with mild-to-moderate hearing loss was intelligible, misarticulation of fricatives and affricates was common, particularly for children with three-frequency pure-tone average thresholds >45 dB HL. In addition, language samples from these children were characterized by frequent semantic and syntactic errors involving the use of complex sentence structures (e.g., imbedded phrases, dependent clauses), bound morphemes (e.g., plurals, possessives), and the unstressed components of speech (e.g., articles). In general, these findings may be related to inaudibility of various aspects of the speech signal as a consequence of hearing loss.

To assess the consequences of mild-to-moderately severe hearing loss, it may be necessary to focus on specific properties of speech that are most likely to be affected by the reduced audibility of speech due to factors such as degree of hearing loss, distance, environmental noise, and the current limitations of amplification systems. In addition, reduced audibility may be expected to impact the acquisition of language. From a developmental perspective, /s/ is known to be of high linguistic importance in the English language. It is the 3rd to 4th most frequently occurring phoneme and serves multiple linguistic functions, denoting plurality, tense, and possessiveness (Denes, 1963; Rudmin, 1983; Tobias, 1959). Among children and adults with hearing loss, /s/ is one of the most frequently misperceived phonemes (Bilger & Wang, 1976; Danhauer, Abdala, Johnson, & Asp, 1986; Dubno & Dirks, 1982; Owens, 1978; Owens, Benedict, & Schubert, 1972). In addition, Elfenbein et al. (1994) have reported that the language samples of children with mild-to-moderate hearing losses often reveal increased errors in both noun and verb morphology (e.g., cat versus cats, keep versus keeps). Studies with children having a positive history of otitis media also have shown a significant reduction in the perception of morphological inflections denoting plurality (Petinou, Schwartz, Gravel, & Raphael, 2001; Teele, Klein, Chase, Menyuk, & Rosner, 1990). It is likely that these findings are related to a reduction in audibility of the fricative noise and/or the formant transition due to the presence of hearing loss. These results suggest that a

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reduction in audibility may have a negative impact on morphological development when the hearing loss is congenital or acquired in early life.

To date, relatively few studies of fricative perception have been conducted with either normal-hearing or hearing-impaired children. Kortekaas and Stelmachowicz (2000) investigated the effects of low-pass filtering on the perception of /s/ (spoken by a male talker) in normal-hearing children (5, 7, and 10 yr olds) and adults. They found that the children required a wider signal bandwidth than did adults to perceive /s/ correctly when stimuli were presented in noise.

In a later study, Stelmachowicz, Pittman, Hoover, and Lewis (2001) investigated the effect of stimulus bandwidth on the perception of /s/ in normal-hearing and hearing-impaired children and adults. In this study, test stimuli were produced by three talkers: a male, a female, and a child. In general, both groups of children performed more poorly than their adult counterparts at similar bandwidths, and both hearing-impaired groups performed more poorly than their normal-hearing counterparts. In addition, significant talker effects for /s/ were observed. For the male talker, optimum performance was reached at a bandwidth of approximately 4 to 5 kHz. For the female and child talkers, performance continued to improve at the widest bandwidth (9 kHz). In general, these findings correspond to the spectral characteristics of /s/ for the three talkers used in the study. Specifically, the peak energy for the male talker occurred at 5 kHz and for the female and child talkers at 9 kHz. Interestingly, unlike previous studies with adults (Ching, Dillon, & Byrne, 1998; Hogan & Turner, 1998), the provision of high-frequency gain in this study did not show a degradation in performance for any of the hearing-impaired subjects.

The close relation between perception and the acoustic characteristics of /s/ may have important implications for the speech and language development of young hearing-impaired children. Even with the most advanced technology, current hearing aids provide relatively little gain above 5 kHz*. Furthermore, acoustic feedback also may limit the amount

*Although manufacturers often report that the upper bandwidth of current hearing aids is >6 kHz, the upper and lower frequency range is defined as -20 dB relative to the average gain at 1000, 1600, and 2000 Hz (ANSI, 1996). Thus, a hearing aid with an average gain of 40 dB would only have 20 dB of gain at the upper frequency limit. In many cases, this may be inadequate to ensure the audibility of /s/. In addition, acoustic feedback will often limit usable gain due to factors such as intentional venting, imperfect seal of the earmold, leaks at tubing joints, and emission from tubing walls (Hellgen, Lunner, & Arlinger, 1999). Acoustic feedback is likely to pose a greater problem for children than for adults due to growth of the ear canal and the close proximity of the hearing-aid microphone to the potential sources of acoustic leakage.

of high-frequency gain that can be attained with infants and young children. These acoustic factors may result in an inconsistent exposure to /s/ across different talkers, situations, and contexts during the early years of life, and thus may influence or delay the formation of linguistic rules.

The overall goal of this study was to determine the accuracy with which hearing-impaired children can detect the inflectional morphemes /s/ and /z/ when listening through hearing aids. It is hypothesized that the performance of the hearing-impaired children will reflect the reduction in signal audibility caused by hearing loss and/or the limited bandwidth of hearing aids. To accomplish this goal, it was necessary to develop a test of morpheme perception that could be used with both normal-hearing and hearing-impaired children. The goal of Part I was to evaluate the performance of normal-hearing children as a function of age to determine the age at which children could perform this task without difficulty. The goal of Part II was to assess the performance of hearing-impaired children on this same test and determine the extent to which degree of hearing loss and/or signal audibility influenced performance.

PART I

METHODS

Participants

Thirty-six normal-hearing children between the ages of 3 yr 9 mo and 5 yr 6 mo were enrolled in this study. Five to six children were recruited for each of seven categories in 3-mo intervals. All children had normal middle-ear function and pure-tone thresholds ≤ 20 dB HL at 0.5, 1, 2, and 4 kHz in both ears.

Test Development

Typically, morphological development is assessed from spontaneous and/or elicited speech samples. This method may confound the interpretation of results for hearing-impaired children where speech production may be delayed or abnormal. To be appropriate for young hearing-impaired children, the task must be simple, the test items must have pictorial representations, and be within the vocabulary of preschool children. Potential test items were selected based on the work of Moe, Hopkins, and Rush (1982). Words with a high frequency of occurrence for first grade children were assumed to be within the repertoire of younger children. Pilot studies then were conducted with 3- to 5-yr-old normal-hearing children to: 1) eliminate test items that could not be easily identified; 2) determine whether

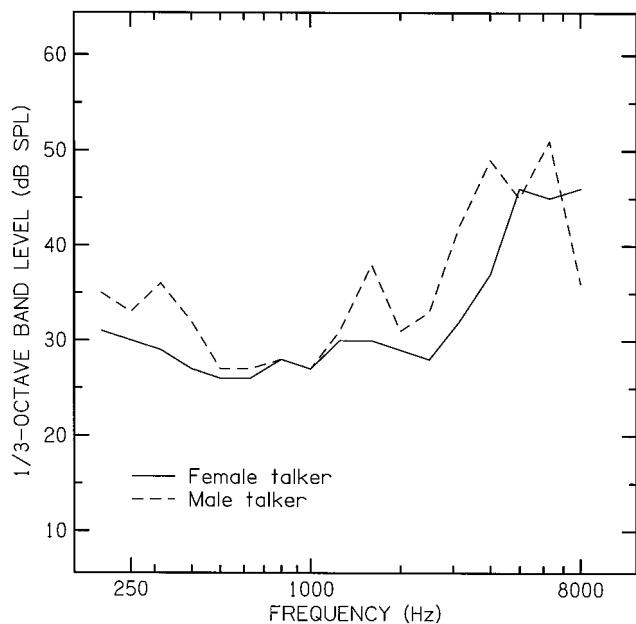


Figure 1. 1/3-octave band analysis of the fricative noise for the male and female talkers. Spectra were obtained using a 20 msec Hanning window with 50% overlap.

the task was age appropriate; and 3) determine the number of practice items needed. The final version used in Part I consisted of two tests, one for the male talker and one for the female talker. Each test consisted of the same 20 unique stimuli (10 plural items and 10 singular items), but the order of presentation was randomized within each version. The test words were one- to two-syllable nouns represented by pictures (see the Appendix). Each page contained two panels with a single picture of the test item in one panel and multiple representations of the same item in the other panel. Singular and multiple forms were randomized across panels.

Both the male and female talkers spoke each test word in isolation. Stimuli were digitized at 22.05 kHz, filtered at 10 kHz, and the rms levels of all test items were equated and converted to a 44.1 kHz sampling rate to create a compact disc. The carrier phrase, "Show me" preceded each test item and the inter-stimulus interval between sentences was 4 sec.

Because the test words were spoken in isolation, the voicing of /z/ was minimal. To determine the amplitude and spectral characteristics of /s/ and /z/, the fricative noise was excised from each test word and concatenated for each talker. Figure 1 shows the 1/3-octave band analysis of the fricative noise for the male and female talkers (using a 20 msec Hanning window with 50% overlap). The peak energy for the male talker occurs between 4 and 6 kHz, while the peak energy for the female talker occurs above 6 kHz. These results are consistent with previous data on the spectral characteristics of /s/ for male and

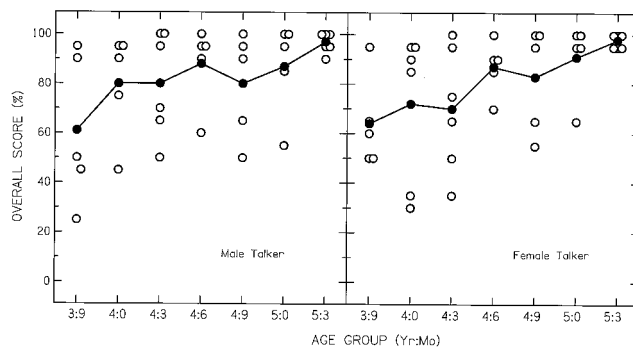


Figure 2. Individual data (open circles) and mean overall scores (filled circles) as a function of age group for the 38 normal-hearing children. The left and right panels show data for the male and female talkers, respectively. Open circles have been offset slightly on the x-axis to minimize overlap.

female talkers (Boothroyd, Erickson, & Medwetsky, 1994; Boothroyd & Medwetsky, 1992; Nittrouer, Studdert-Kennedy, & McGowan, 1989).

Procedure

Prior to testing, each child was given several practice items on 4-by-5 inch laminated cards. These items were different than the ones used in the actual test and were administered in a face-to-face setting with both auditory and visual cues. The child was first shown a picture and asked to verbally identify the item (e.g., boat) to ensure that it was within his or her vocabulary. Then the child was asked to identify the plural form of the same picture. Finally, the child was shown both the plural and singular forms of a practice item and asked to identify the target (e.g., Show me boats) by pointing to the correct picture. During this practice session, the child was given feedback regarding performance. Once the researcher was certain that the child understood the task, data collection began.

Each child was seated at the calibrated position in a double-walled sound booth at a 0 degree azimuth to the loudspeaker. The output of the compact disc player was routed to one channel of a clinical audiometer (Grason Stadler, Model 61) and test signals were presented in an auditory only mode at 65 dB SPL. The order of presentation (male versus female talker) was counterbalanced across children. The child's task was to point to the correct test item.

RESULTS

The normal-hearing children were grouped into seven age categories in 3-mo intervals from 3 yr, 9 mo to 5 yr, 3 mo. Figure 2 shows the individual data (open circles) and mean overall scores (filled circles) for the 38 normal-hearing children as a function of age group. Results for the male and female talkers

are shown in the left and right panels, respectively. Inter-subject variability is high until 5 yr 3 mo, at which time performance was $\geq 90\%$ for all children in this age group. Mean performance was above chance level (50%) even for the youngest participants and gradually increased as a function of age. The overall scores as well as the scores for both singular and plural test items were arcsine transformed and a repeated measures analysis of variance (ANOVA) was conducted. The within-subjects factors were talker (male versus female) and form (plural versus singular test items). Results revealed no significant main effects for talker [$F(1,37) = 0.004$, $p = 0.949$] or form [$F(1,37) = 0.141$, $p = 0.709$], suggesting similar performance for plural and singular test items as well as talkers.

PART II

METHODS

Participants

Forty children (5 to 13 yr) with bilateral sensorineural hearing loss participated in this study. All children were oral communicators and were mainstreamed in the school system. Based on the results of Part I, the minimum age for inclusion in this portion of the study was 5 yr. Specifically, since the oldest normal-hearing children achieved performance $\geq 90\%$, it was assumed that poor performance by any of the hearing-impaired children could be interpreted as either an immediate (inaudibility) or long-term (delayed language) consequence of hearing loss, and not due to an inability to perform the task.

To assess the relation between degree of hearing loss, signal audibility, and test performance, participants with widely varying degrees and configurations of hearing loss were recruited. Although symmetry of hearing loss also varied somewhat across children, all were aided binaurally.

Thresholds were obtained at octave and intra-octave frequencies (if indicated) using either supra-aural (TDH-50) or insert earphones (ER-3A). In the majority of cases (27 children), thresholds were obtained on the day of test. In many instances, children had been tested multiple times over several years and had a long-standing history of stable thresholds. When children were being seen for multiple appointments on the day of test (e.g., ENT, speech-language, genetics), full audiograms could not be completed due to time constraints. For 12 children, a complete audiogram had been obtained within 1 to 6 mo and for one child, the audiogram had been obtained 9 mo prior to the study. Figure 3 shows thresholds (in dB HL) for the right and left

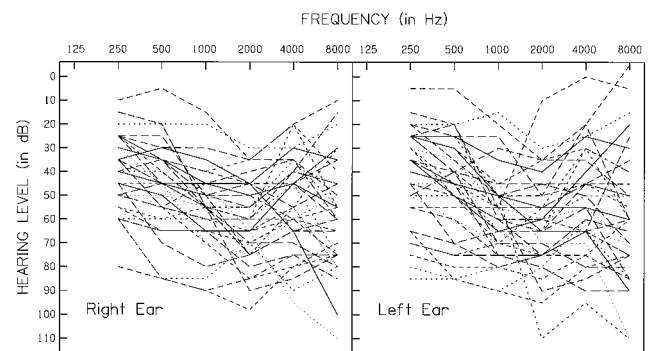


Figure 3. Thresholds (in dB HL) for the right and left ears of the hearing-impaired children.

ears of all participants. Table 1 shows the mean and standard deviation of subject ages, better ear three-frequency averages (PTA), and thresholds at 4 kHz.

Hearing Aid Characteristics

The goal was to include a group of typical hearing-impaired children that had been fit with hearing aids in accordance with best practice. As such, all children had been fitted using the Desired Sensation Level Procedure (Seewald, Cornelisse, Ramji, Sinclair, Moodie, & Jamieson, 1997). This procedure is audibility based and recommends more high-frequency gain than alternative fitting strategies. The hearing-aid fittings represented a wide range of circuitry options. Although attempts were made to match target gain and output values as closely as possible, factors such as circuit type, electroacoustic limitations, and acoustic feedback often resulted in less high-frequency gain than was recommended.

Prior to data collection, 2-cm³ coupler gain values were obtained at each child's use settings using a 65 dB SPL speech-weighted signal, whereas maximum output was obtained using a 90 dB swept pure-tone signal. These values were compared to previously obtained values to ensure that the hearing aids were operating properly and meeting target values as well as possible. To facilitate the conversion of coupler values to real-ear output (for audibility calculations), real-ear-to-coupler differences (RECDs) were obtained

TABLE 1. Descriptive statistics (mean, standard deviation, and range) for the 40 hearing-impaired children.

	Age (yr)	3-Frequency PTA (0.5, 1.0, & 2.0 kHz)	4-kHz Threshold
Mean	8.7	52	48
SD	2.1	15	19
Range	5.0–13.2	18–90	0–85

The pure tone average (PTA) and 4-kHz thresholds (in dB HL) are shown for the better hearing ear.

as a function of frequency using the procedure described by Moodie, Seewald, and Sinclair (1994).

Aided Audibility Calculations

Traditional measures of audibility, such as the Speech Intelligibility Index (ANSI, 1997) are not adequate to estimate the audibility of brief speech segments. These procedures are designed to calculate audibility of the long-term spectrum of continuous discourse, words, or nonsense syllables. In addition, the calculations typically include frequency-dependent weights, known as importance functions, which reflect the relative importance of each frequency region to the perception of the specific speech materials. For example, low frequencies are most important for the perception of continuous discourse and high frequencies are most important for nonsense syllables (Studebaker & Sherbecoe, 1993). Frequency importance functions also are available for phonemic features such as nasality and sibilance but these are not intended to represent *individual* speech sounds (Duggirala, Studebaker, Pavolic, & Sherbecoe, 1988).

The issue of importance functions becomes complex in the case of listeners with hearing loss. For example, adults who gradually lose their hearing may develop unique strategies to compensate for reduced audibility in certain frequency regions. Similarly, children with prelingual hearing loss may learn to use whatever aspects of the signal are available to them to perceive speech. The success of cochlear implants supports the notion that listeners with hearing loss can learn to use cues that may differ substantially from those used by listeners with normal hearing.

The audibility calculations used in the current study were designed to meet the following criteria: 1) provide an estimate of fricative audibility referenced to the ear canal, 2) make minimal assumptions regarding the frequency region of importance for /s/ and /z/, and 3) account for binaural differences in aided signal audibility.

Figure 4 shows an example of the amplified spectrum of /s/ in relation to the thresholds of one child. The circles denote thresholds and the dashed line represents the upper 1% of the fricative noise amplitude distribution in each 1/3-octave band after processing by the hearing aid. The shaded region denotes the portion of the fricative noise that was audible to this child. To provide a quantitative measure of audibility for each child, the following procedure was used. For each talker, stimulus levels (StL) were calculated using the following formula:

$$\text{StL}_i = \text{TOB}_i + \text{HRTF}_i + \text{RECD}_i + \text{HA gain}_i$$

where TOB is the 1% peaks of the fricative in each 1/3-octave band, i is the center frequency of each

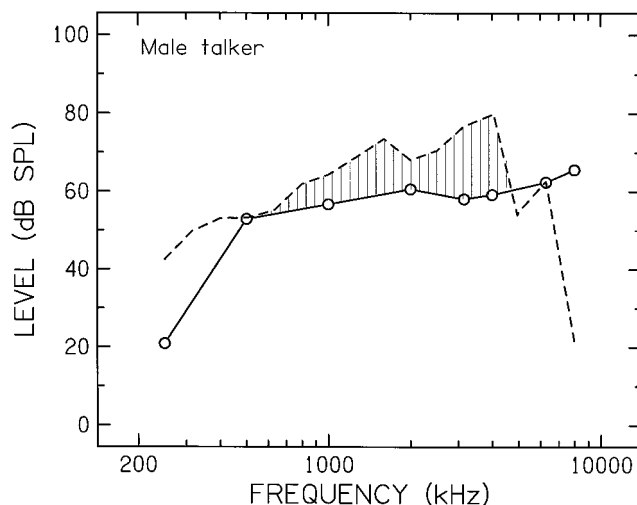


Figure 4. Amplified spectra of /s/ in relation to the thresholds (open circles) of one participant. Shaded region denotes the audible portion of the signal.

TOB from 1 to 8 kHz, HRTF is the head-related transfer function (Bentler & Pavlovic, 1989), RECD is the real-ear-to-coupler difference, and HA gain is the 2-cm³ coupler gain measured with a 65 dB composite weighted noise signal.

The sensation level (SL) in each 1/3-octave band was calculated by subtracting the sound pressure level at threshold from the stimulus level. These calculations were made for each ear independently. Because it was assumed that, when listening binaurally, children would use the most audible acoustic information available to them, the final audibility calculations were based on the highest sensation level at each frequency, regardless of ear. That is, for an asymmetrical hearing loss where sensation levels were highest in the left ear in the 1 to 3 kHz range and highest in the right ear in the 4 to 8 kHz range, SL_{bin} would be based on the left ear at mid frequencies and the right ear at high frequencies. SL_{bin} was then used to calculate a binaural aided audibility index (AAI_{bin}) with the following formula:

$$\text{AAI}_{\text{bin}} = \frac{1}{20} \sum_{i=1}^8 (\text{SL}_{\text{bin}}) W$$

where SL_{bin} is the maximum sensation level at each frequency (regardless of ear) and the importance function (W) is represented by equal weights (0.10) in the ten 1/3-octave bands from 1 to 8 kHz. The sum of the weighted sensation levels was restricted to a 0 to 20 dB range by the multiplier 1/20, because a previous study (Stelmachowicz et al., 2001) showed that the dynamic range for short segments of speech (particularly fricatives) is less than the 30 dB range used in audibility calculations of the long-term spectrum.

Procedure

Pilot data with children >5 yr of age suggested that these older children might be able to remember which test items were either singular or plural across talkers. To minimize this possibility, the male and female versions were combined, randomized, and preceded by 13 practice items that were not scored. In addition, seven irregular forms (e.g., child/children), spoken by the male talker only, were interspersed with the 13 practice items to determine whether the concept of plurality could be recognized when fricative noise was not the cue. The final test consisted of 60 test items.

The hearing-impaired children wore their personal hearing aid(s) at their normal use settings. In all other respects, the procedures and test administration were identical to those used for the younger normal-hearing children.

RESULTS

Although the irregular form generally is acquired later than simple plurals, the vast majority of hearing-impaired children appeared to have no difficulty with these items. Performance on the irregular forms was high, with a mean of 97.5% ($\pm 1.1\%$ SD), suggesting that these children had a clear concept of plurality.

Figure 5 shows the results for the morpheme perception task for the 40 hearing-impaired children. In this figure, individual data for each talker are shown as a function of age. The top panels show the overall scores while the lower panels show scores for the plural words only. The left and right panels show the results for the male and female talkers, respectively. For both talkers, there is considerable variability in the overall scores across age and no obvious age-related trends. Slightly lower mean performance was observed for the female talker (85%) compared to the male talker (90%) and greater variability for the female talker. When only the plural test items were considered, the inter-subject variability was greater than that observed for the overall scores. In addition, larger performance differences were observed between the male (87%) and female talker (79%) compared to those seen for the overall scores. A repeated-measures ANOVA was conducted as in Part I. In contrast to the results for the normal-hearing children, this analysis revealed significant main effects for talker ($F(1,39) = 12.4, p < 0.001$) and form ($F(1,39) = 7.8, p < 0.01$), indicating poorer performance for the female talker and poorer performance for the plural words. No talker \times form interaction was found, suggesting similar effects were found for each within subjects factor.

To determine the extent to which individual dif-

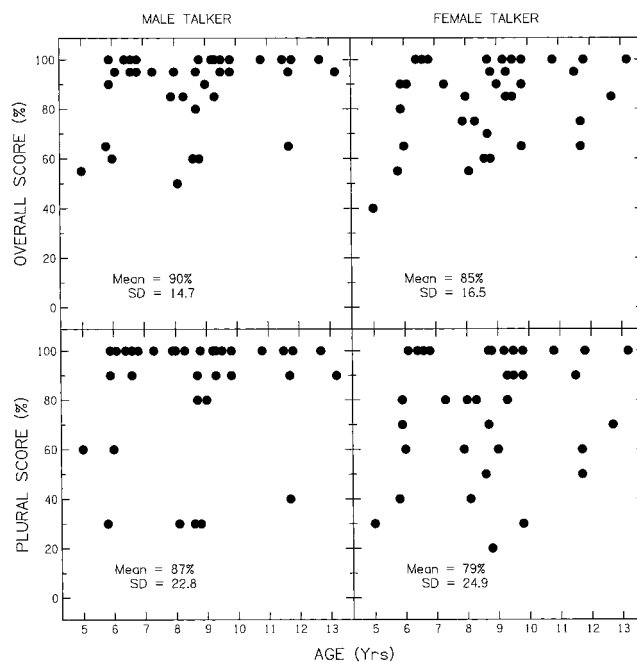


Figure 5. Overall scores (top panels) and plural scores (lower panels) for the 40 hearing-impaired children as a function of age. The left and right panels show data for the male and female talkers, respectively. Mean and standard deviations are shown in each panel.

ferences influenced performance, a factor analysis was performed for each talker. Variables were age at test, age of amplification, performance for irregular forms, AAI_{bin} (based on 1 to 8 kHz), hearing level (HL) at octave frequencies from 0.25 to 8 kHz, and sensation level (SL) of the fricative noise from 0.25 to 8 kHz. Although fricative noise is primarily high frequency in nature, this broader range of frequencies was used to determine whether amplified low-frequency noise might have been a cue to the presence of /s/ or /z/ for some participants. This analysis reduced the data into four principal components that explained a total variance of 78.8% for the female talker and 78.5% for the male talker. These components were: 1) AAI_{bin} , SL at 2 kHz, and HL at 2 to 4 kHz; 2) SL in the 0.25 to 0.5 kHz region and HL at 0.25 kHz; 3) SL and HL at 8 kHz; and 4) the child's age at test. The percent of variance accounted for by each component is given in Table 2. These components do not represent the relation between these variables and performance. To determine whether any of the identified principal components correlated with performance, an additional analysis was conducted. In this analysis, performance for the plural words only was correlated with the factor scores assigned to each child and principal component. Asterisks in Table 2 denote cases where statistical significance was reached. These results show a significant relation between performance for the

TABLE 2. Percent of variance accounted for by components 1–4 for the male and female talkers.

Component	Description	Male Talker	Female Talker
1	AAI _{bin} ; SL @ 2 kHz; HL @ 2-4 kHz	42.7*	43.3*
2	SL @ .25-.5 kHz; HL @ .25 kHz	16.7	16.4
3	SL & HL @ 8 kHz	10.2	10.0*
4	Age	9.0	9.2

Cases where the correlation between the principal component and performance reached statistical significance (0.01 level) are noted by asterisks.

male talker and the hearing and sensation levels in the 2 to 4 kHz range. A similar relation was revealed for the female talker with the addition of hearing and sensation levels at 8 kHz. These results are consistent with the acoustic spectra of each talker and suggest a strong relation between the physical acoustics of the stimuli and perception.

For the talkers in this study, the peak energy of the male and female fricatives occurred at 4 to 6 kHz and 5 to 8 kHz, respectively. In general, however, the frequency response of the children's hearing aids provided minimal gain above 4 kHz. Figure 6 shows the sensation level of the fricative at 4 kHz as a function of degree of hearing loss with talker as the parameter. The solid lines show a best fit to the data. Although sensation level decreases with increasing hearing loss for both talkers, there is con-

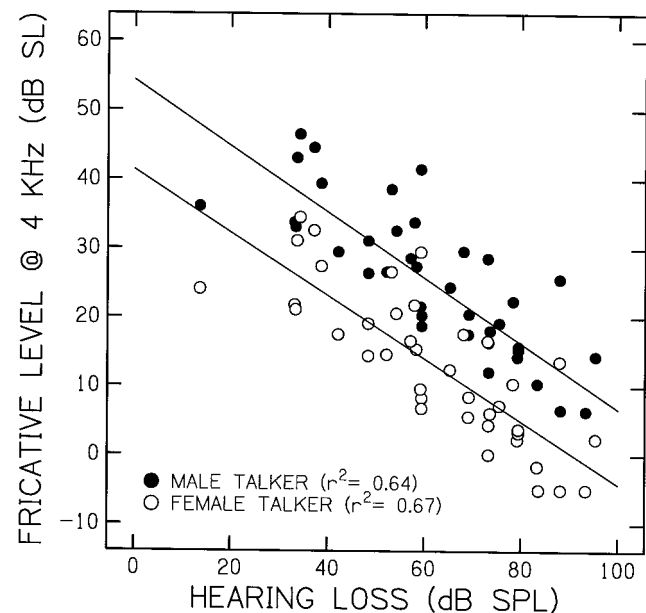


Figure 6. Sensation level of the fricative noise as a function of degree of hearing loss for the 40 hearing-impaired children. Filled and open symbols represent data from the male and female talkers, respectively. Solid lines represent the best fit to the data for each talker and the r^2 values are given.

siderable intersubject variability. Some children with less hearing loss have lower sensation levels than children with greater hearing loss. This variability is most likely due to the limitations imposed by the children's current hearing aids and problems with acoustic feedback that are often encountered when fitting children. On average, however, a difference of approximately 12 dB is observed between the two talkers. These results are consistent with the spectral differences between the two talkers at 4 kHz (i.e., 12 dB). At higher frequencies (not shown), the overall sensation levels decreased for both talkers and values <0 were often observed, presumably due to an interaction between hearing-aid response, hearing sensitivity, and talker spectra. Based on the sensation level differences at 4 kHz, one would predict poorer performance for the female talker if judgments were made solely on the basis of audible energy in the high-frequency region. This is somewhat consistent with the performance differences observed between talkers (5% for the overall score and 8% for the plural scores).

General Discussion

The first part of this study revealed that the normal-hearing children were able to identify the presence or absence of /s/ and /z/ in the task devised for this study by 5 yr 3 mo of age. It is important to recognize that the performance of the normal-hearing children did not necessarily reflect the acquisition of morphemes, but rather their ability to perform this particular perceptual task. Although the picture-pointing format appears to be straightforward, some of the youngest normal-hearing children had difficulty with the task. For example, when asked to point to a singular item such as "duck," some children would point to a *particular* duck in the group of "ducks." The data from the normal-hearing children are consistent with previous reports based on comprehension tasks. Children acquire bound morphemes in expressive language fairly early in life but they are unable to demonstrate this knowledge through comprehension tasks until much later. Specifically, when production was used as a measure of acquisition, 90% correct usage of /s/ to denote plurality was reported in obligatory contexts for children in the 27 to 30 mo age range (de Villiers & de Villiers, 1973). When a comprehension task was used, only 80% correct usage of the plural /s/ was seen in 6-yr-old normal-hearing children (Miller & Yoder, Reference Note 1).

The second part of this study revealed highly variable performance by the hearing-impaired children. Mid-frequency audibility (2 to 4 kHz) appeared to be most important for perception of the fricative

noise for the male talker while a somewhat wider frequency range (2 to 8 kHz) was important for the female talker. This is consistent with the talker effects observed for the hearing-impaired children. Specifically, plural test items spoken by the female talker showed the highest error rate. Interestingly, significant talker and form differences were not observed for the normal-hearing children. This finding may have important implications for speech and language development in young hearing-impaired children. In the early years, most infants and young children spend the majority of their waking hours with their mother or other female caregivers. Since the acoustic characteristics of the female /s/ and /z/ in the current study were similar to previously reported data, findings suggest that the audibility of /s/ and /z/ produced by female talkers may result in inconsistent exposure to these speech sounds. That is, a child may hear Dad talking about their family "cats" but Mom may appear to always talk about the family "cat." What appears to be inconsistent usage by adults may delay the formation of rules (e.g., understanding that "two" or "many" will often be followed by a plural noun) and/or result in inconsistent usage by the hearing-impaired child. Longitudinal studies of morpheme acquisition in younger hearing-impaired children are needed to fully understand the importance of high-frequency amplification in this group.

It is important to recognize, however, that audibility of fricative noise is not the only cue to perception of plurals. In some cases, vocalic transitions from the vowel into the fricative noise may be a cue to perception, although transitions vary across vowels and talkers, and generally are absent when the fricative noise is preceded by a stop (e.g., cats). Similarly, visual cues can be used to perceive the final /s/ or /z/ in some cases. However, these supplementary cues are inconsistent in actual conversations. The fact that hearing-impaired children demonstrate a delay in morphological development relative to normal-hearing children (Elfenbein et al., 1994; Petinou et al., 2001; Teele et al., 1990) suggests that the available cues are insufficient.

It is important to caution that the results from the current study may not apply to all children or listening conditions. While the spectral characteristics of the /s/ for the two talkers in this study were similar to previously reported mean data, it is likely that individual differences would have a substantial influence on fricative perception in typical listening situations. In addition, the AAI_{bin} calculations assumed that the listener would utilize the most audible signal for perception, regardless of ear. In typical listening situations, the head shadow effect may complicate the situation. Finally, in noise, re-

verberation, or when listening at a distance, one would expect young children to experience even more difficulty perceiving fricatives than was observed in this study.

Results of the current study may have important implications for clinical practice. Currently, the provision of adequate gain in the 6 to 8 kHz range is difficult, particularly for infants and young children where acoustic feedback is often a complicating factor. Improvements in earmold fabrication techniques and materials, as well as feedback reduction schemes may help to improve the audibility of speech in the high frequencies. At present, it is not clear whether advanced hearing-aid circuitry can increase the audibility of high-frequency speech components or whether enhanced audibility will necessarily improve the perception and production of /s/. Prospective longitudinal studies of infants whose hearing loss was identified early are needed to address these issues.

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APPENDIX

Plural Items	Singular Items
Apples	Ball
Babies	Bear
Beds	Bike
Books	Cake
Cars	Cat
Flowers	Dog
Ghosts	Hat
Rabbits	Shirt
Shoes	Star
Trees	Truck