Longitudinal Study of Speech Perception by Children with Cochlear Implants and Tactile Aids: Progress Report

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A longitudinal study is underway to examine the speech perception abilities of profoundly hearing-impaired children who use either a cochlear implant or tactile aid. The performance of these children, who do not benefit from conventional amplification, is being compared to a third group of subjects who have residual hearing and use hearing aids. A battery of measures is employed to assess a range of speech perception abilities. Initial findings obtained with 12 implant users, 3 tactile aid users, and 1 hearing aid user showed large individual differences among the subjects with implants. The highest performer was a single-channel implant user who demonstrated closed-set speech recognition. The performance of the three users of the tactile aid tended to be uniformly poor. No clear cut performance trends were observed as a function of age of onset of the hearing loss.

Historically, all children with a hearing loss of 90 dB HL or greater were classified as "deaf" (cf. Hudgins & Numbers, 1942) because it was assumed that everyone with this degree of hearing loss exhibited similar speech perception abilities. Over the years, however, clinical observation and empirical data have challenged this assumption. Today, it is generally accepted that there are differences in speech perception abilities among profoundly hearing-impaired listeners.

Some individuals with profound hearing losses do not hear sound at all. Rather, they respond to acoustic stimuli on the basis of vibrotactile sensation (Boothroyd & Cawkwell, 1970; Erber, 1972). These individuals show responses to pure-tone stimuli only in the low frequencies at high intensity levels. They are able to perceive only the time and intensity patterns of speech through the auditory channel but not rapid spectral changes necessary to perceive most of the phonemic aspects of speech (Erber, 1972).

Data collected by Boothroyd (1984) suggest that children whose losses exceed 115 dB HL (three-frequency average) respond on the basis of vibrotactile sensation. Boothroyd concluded that these children demonstrate no auditory speech perception skills. In contrast, children with thresholds of 90-104 dB HL are able to use frequency-dependent information in the speech signal to perceive vowel and consonant contrasts on a closed-set word recognition task. For hearing losses ranging from 104 to 114 dB HL, Boothroyd reported that no clear-cut interpretation of the children's auditory perception abilities could be made from the data.

Profoundly hearing-impaired children who have no residual hearing receive negligible benefit from conventional hearing aids. The only recourse for these children to have access to acoustic speech stimuli is to use a sensory aid that does not rely on cochlear function to transmit information about sound to the central nervous system. Cochlear prostheses, which stimulate the auditory nerve directly, have been used with children who receive no benefit from hearing aids since 1980 (Berliner & Eisenberg, 1985). The use of implants with children is controversial because surgery is required and the degree of benefit derived from them has not been clearly established.

An alternative to the cochlear implant is the use of a tactile aid, which is noninvasive. Although extensive research has been conducted on the perception of sound via the skin (e.g., Verillo, 1985) and perception of speech with various tactile or electrocutaneous devices with artificially deafened adults (e.g., Reed, Durlach, & Braida, 1982), limited information is available on the speech perception abilities of profoundly hearing-impaired children with tactile aids. Case studies have shown an improvement in the language skills of two preschool children with no residual hearing after using a single-channel vibrotactile aid (Geers, 1986; Proctor & Goldstein, 1983). Friel-Patti and Roeser (1983) observed an improvement in the communication skills of a small group of profoundly hearing-impaired children who used a multichannel tactile device. From the audiometric data presented in the Friel-Patti and Roeser (1983) study, it is unclear whether the profoundly hearing-impaired children who participated in their study had any residual hearing.

Several studies have compared the speech perception performance of profoundly hearing-impaired adults with a tactile aid and with a cochlear implant (Dowell, Martin, Clark, & Brown, 1985; Skinner et al., 1988). In these studies, the adults used the tactile aid prior to receiving a cochlear implant. A potential problem with this design is that an order effect can occur. Further, it has been argued that subjects who use a tactile aid before receiving an implant are more motivated to use the implant than the tactile aid. Within-subject device comparison is difficult, however, when one of the devices under study is invasive. An alternative approach is to use a between-subject comparison in which performance is compared across individuals who have similar characteristics but who use different devices. A problem with this design is that it is nearly impossible to match the subjects perfectly across device groups. There appears to be no published report of the use of either a within- or between-subject study comparing the relative benefits of a cochlear implant and tactile aid in profoundly hearing-impaired children who have no residual hearing.

Research on speech perception by profoundly hearing-impaired subjects has highlighted the need to use procedures which assess a range of skills. Investigators have developed measures to evaluate the children's ability to make use of the time and intensity patterns of speech, and changes in fundamental frequency associated with suprasegmental aspects of speech (Boothroyd, 1984; Erber & Alencewicz, 1976; McGarr, 1987; Thielemeir, Tonokawa, Peterson, & Eisenberg, 1985). Further, data are available on profoundly hearing-impaired children's perception of phonetic features in nonsense syllables or words using a closed-set format (Boothroyd, 1984; McGarr, 1987; Smith, 1975). Measures such as these are useful in evaluating the performance of profoundly hearing-impaired children with sensory aids as well as assessing their auditory capabilities in the unaided condition.

A longitudinal study is underway to examine the speech perception abilities of profoundly hearing-impaired children with no residual hearing who use either a cochlear implant or tactile aid. The performance of the children with implants and tactile aids also will be compared to that of their profoundly hearing-impaired peers who do have residual hearing and derive benefit from conventional hearing aids. The purpose of this paper is to present an overview of the longitudinal study and to report initial findings on the performance of a small number of subjects.

OVERVIEW OF LONGITUDINAL STUDY

Experimental Protocol

There are two groups of experimental subjects: one uses a single-channel (3M/House) or multichannel (Nucleus 22-Channel Cochlear Implant System) implant; the other a tactile aid (Tactaid II). The subjects in the two experimental groups have been fitted with an implant or tactile aid because they have no residual hearing and do not benefit from conventional hearing aids. The criteria used to determine inability to benefit from amplification are the same as those used by other implant teams (Berliner & Eisenberg, 1985). Typically, the children show no response to pure-tone stimuli at the audiometric limits in the sound field with appropriate hearing aids, or respond at levels suggestive of vibrotactile rather than auditory sensation (Boothroyd & Cawkwell, 1970). Other criteria for inclusion in the experimental groups are: (a) absence of gross personal maladjustment, as demonstrated by appropriate psychological tests and interviews; (b) consent to complete an extensive rehabilitation program; (c) supportive home situation, as determined by parent interview; and (d) school environment supportive of the development of auditory skills (Miyamoto, McConkey, Myres, Pope, Groom, & Harmon, 1985).

The subjects with cochlear implants have received their devices at the Indiana University School of Medicine through physician referral or parental request. Currently, there are 34 children who have received an implant at this facility. Of these, 26 have received the 3M/House single-channel implant and the remainder have received the Nucleus 22-Channel Cochlear Implant System. The Nucleus device has been used almost exclusively since it became available for children. The children range in age from 4 to 18 years with onset of deafness ranging from birth to nearly 7 years of age. The majority of them live outside of Indiana.

The subjects with tactile aids, who also have no residual hearing, have been recruited or have been referred for their device by parents or professionals. Each tactile-aid wearer is selected so as to match a child with an implant (single- or multichannel) as closely as possible with respect to age at onset of deafness, length of acoustic deprivation (i.e., time between onset of deafness and receipt of device), chronological age, and home and school environment. There are 18 subjects who use a tactile aid. All received the Tactaid II device with the two-channel vibrator array worn either on the wrist or sternum. This device has been selected for evaluation because it appears to be used most frequently with profoundly hearing-impaired children.

A third group of subjects consists of children who have residual hearing and receive benefit from conventional hearing aids. The audiological criterion used to select these children is a three-frequency pure-tone average of 90-104 dB HL. This criterion is based on the data obtained by Boothroyd (1984) which showed children with this degree of loss could make use of frequency changes in speech. Therefore, these children are not considered to be candidates for an implant or the Tactaid II. Each subject in the hearing aid group is matched to a pair of subjects with an implant and tactile aid with respect to age at onset of deafness, chronological age, and home and school environment. The subjects with hearing aids typically have a shorter period of acoustic deprivation than the subjects in the experimental groups because they are fit with their sensory aid relatively soon after the onset of the hearing loss.

The performance of the subjects with hearing aids is compared to that of the subjects who use an implant or tactile aid. It has been hypothesized that the highest level of performance achievable with an implant or tactile aid might equal but will not exceed that of profoundly hearing-impaired peers who have residual hearing and use hearing aids (Osberger, 1989).

The subjects in the two experimental groups are tested the first day they receive their device and at six-month intervals thereafter. The subjects with hearing aids are evaluated only once a year because it has been hypothesized that smaller learning effects will occur with this group than with the subjects in the two experimental groups.

Training

The subjects in both experimental groups receive intensive training to help them learn to use their device. The training, which is initiated immediately after the fitting of the device (the time of hook-up for the implant subjects), is continued throughout the first year of device use. It consists of approximately 30 hours of individual rehabilitation which addresses the auditory, speech, and language needs of each child. This training is in addition to that which the child receives through his or her school program. For the children with implants, additional time is needed to check and set the device, especially for the users of the multichannel implant. A training curriculum has been designed based on existing programs (Eisenberg, 1983; Windle & Stout, 1984) and materials developed as part of this research program. The children with hearing aids receive no training in addition to that provided through their school programs.

All children with implants receive their training at the Indiana University School of Medicine from a group of four clinicians, as do the children with tactile aids who are within commuting distance of the medical center. The remainder of the children with tactile aids receive their training from a speech-language pathologist or audiologist in the city where the child lives. These professionals have extensive experience in performing this type of work with profoundly hearing-impaired children and have been hired as consultants for this purpose. Packets of training materials, demonstration videotapes, and supervised on-site training sessions have been used to ensure that the out-of-state subjects with tactile aids receive training similar to that provided the subjects with implants. The majority of out-of-state subjects with a tactile aid are being trained by two clinicians, who live in the same city where the second author resided during the first phase of the study.

Speech Perception Hierarchy

The tests used in this study sample a range of perception skills and response tasks. The tasks range from auditory-only discrimination of acoustic changes between speech features to auditory-only comprehension of simple phrases. Some testing is performed live voice with the examiner seated behind the child approximately three feet from the microphone of the child's device. For other tests, recorded stimuli are presented in the sound field at 70 dB SPL with the child seated approximately three feet in front of the loudspeaker. The following listing indicates the order of test administration.

Discrimination Test. The Change/No Change test is designed to assess detection of an acoustic change in a suprasegmental or segmental feature in a string of monosyllables. The test was developed as an alternative to word recognition tasks which are beyond the capabilities of many implant and tactile aid users. The paradigm is based on that of Kuhl (1980), used to assess the perceptual skills of infants, as modified by Sussman and Carney (in press). There are 10 subtests, each of which contrasts a particular feature of speech: syllable length (short/long), syllable intensity (loud/soft), intonation (statement/question), fundamental frequency (steady/changing contour), talker gender (male/female), vowel height (/bi/ vs. /ba/), vowel place (/bi/ vs. /bu/), consonant manner (/da/ vs. /za/), consonant voicing (/ba/ vs. /pa/), and consonant place (/ba/ vs. /ga/). The stimuli are spoken by an adult male, digitized, and manipulated so that each set of stimuli varies only with respect to the feature of interest.

Each subtest has 15 trials with each trial consisting of a string of 10 syllables. There are 5 *no-change* trials and 10 *change* trials. For the *no change* trial, the 10 stimuli are the same. For the *change* trials, the last five stimuli differ from the first five. The child is instructed to raise his or her hand or hit a bell when a change occurs. Thus, this format requires that the child provide a response on *change* trials but not on the *no-change* trials. If a child is unable to understand this concept and be trained to the task, a different response format is used. In this case, the child is asked to respond verbally after each trial if the string of 10 stimuli are the same or different.

Recognition Tests. The following four tests are administered live voice. The Monosyllable-Trochee-Spondee (MTS) test (Erber & Alencewicz, 1976) consists of 12 pictured nouns with three different stress patterns. Each item is presented two times in random order and the child's pointing responses are scored for stress-pattern categorization and word identification.

The Minimal Pairs test was developed for this project. It consists of 20 pairs of pictured words with members of a pair differing in one of the following features: vowel height, vowel place, consonant manner, consonant voice, and consonant place. Each word in a pair serves as the target and each target is presented two times, for a total of 80 items. The child points to the picture which represents the word spoken by the examiner.

The Hoosier Auditory Visual Enhancement (HAVE) test was developed for the project to evaluate integration of visual and auditory information. The assumption is that children who use implants or tactile aids will need information from both the auditory and visual modalities to comprehend speech in everyday situations. The test consists of 10 sets of three items such as *man, pan, fan.* Two of the items are visually similar and are considered to be homophenous (*man, pan*) whereas the remaining one is visually distinct (*fan*). On a given trial, one of the homophenous words is presented with both auditory and visual cues (only the two homophenous words are ever used as targets). The items are pictured and the child points to the word produced by the examiner. Each item is scored on the basis of (a) visual correctness (e.g., the child selects *man* or *pan*) and (b) word correctness (the child correctly selects the target because both auditory and visual cues are perceived accurately). If a subject relies only on visual cues, then the visual score will be 100% when speechreading is accurate and near chance (33%) when speechreading is not reliable. The word score also will be no better than chance for a poor speechreader, but at least 50% for a good speechreader. If the word score is greater than 50%, it indicates that the child has used auditory as well as visual cues. There are 10 sets of words, with each homophenous item serving as the target once, for a total of 20 items.

The Simple Commands and Questions test was developed for the project to assess understanding of familiar phrases used in everyday situations. An open-set format is used with pretest familiarization of item topics. Ten items first are presented with combined auditory and visual cues. If at least one item is recognized correctly, then another list of 10 items is presented in the auditory-alone condition.

If a child achieves a score of 60% or higher on the Minimal Pairs test, two recorded tests are administered. One test is the Speech Pattern Contrast Test (Boothroyd, 1984) which assesses identification of suprasegmental or segmental features using a forced-choice testing format. The other recorded test is the NU-CHIPS (Elliott & Katz, 1980) which is commercially available. It samples perception of isolated words using a four-alternative forced-choice format.

INITIAL FINDINGS

The battery of tests has been administered to a small number of subjects. Pre- and post-test results are not available for every child because many of the tests were developed after some of them received their device. Also, more data are available for the children with the single-channel implant because they entered the study earlier than the subjects with the other devices. Data are presented for those subjects who have the most complete data set: 11 subjects with the 3M/House device, 1 subject with the Nucleus 22-Channel Cochlear Implant System, and 3 subjects with the Tactaid II.

Subjects

For the purposes of this report, the subjects were divided into three groups according to age at onset of deafness. Group 1 consists of subjects whose hearing loss is congenital; Group 2 consists of subjects with early acquired hearing loss (less than 3 years of age) and a short period of deprivation (less than 4 years); and Group 3 consists of subjects with late acquired losses (after 4 years of age).

Background information on the subjects appears in Table 1. The subjects form a heterogenous group with respect to age fit with the implant or tactile aid, age at onset of deafness, length of acoustic deprivation (i.e., length of time from onset of deafness to receipt of device), and communication methodology. This degree of inter-subject variability is not unique to this subset of children but is typical of the profoundly hearing-impaired population in general.

Two of the subjects with acquired losses (SAI and SCD) were considered to function like children with congenital losses because of the long period of acoustic deprivation that they experienced prior to receiving their implant. That is, it was assumed that the advantage of normal auditory experiences would not compensate for the long period of time that both of these subjects had no access to acoustic speech information. The data reported by Eisenberg, Iler-Kirk, Thielemeir, Luxford, and Cunningham (1986) which showed that the highest performers with the single-channel implant had the shortest period

Table 1
Characteristics of Subjects

Subject	Device	Age at Onset	Length of Deprivation	Age Fit	Length of Use	Communication Mode
Group 1						
SAF	3M/House	Birth	4-5	4-5	4-1	Cued Speech
SAE	3M/House	Birth	5-1	5-1	2-5	Total Communication
SAG	3M/House	Birth	8-5	8-5	2-6	Total Communication
SAI	3M/House	0-10	10-7	11-5	4-4	Total Communication
SCD	3M/House	2-3	10-7	12-10	2-5	Oral
SBU	Nucleus	Birth	10-11	10-11	0-9	Cued Speech
SAZ	Tactaid II	Birth	10-5	10-5	1-1	Total Communication
SBI	Tactaid II	1-0	7-6	8-6	4-4	Total Communication
SAR	Hearing Aid	Birth	3-6	3-6	2-8	Oral
Group 2						
SBE	3M/House	0-6	2-7	3-1	1-3	Total Communication
SBR	3M/House	1-4	2-11	4-3	1-3	Total Communication
SDB	3M/House	2-0	3-11	5-11	1-4	Total Communication
SBJ	3M/House	2-9	2-7	5-4	1-9	Total Communication
Group 3						
SBC	3M/House	5-8	0-8	6-4	3-5	Oral
SBZ	3M/House	5-4	0-10	6-2	1-9	Oral
SBT	Tactaid II	4-0	1-6	5-6	3-2	Total Communication
SCT	Tactaid II	19-0	3-0	21-0	5-0	Oral

Note. Age and times are expressed in years and months.

of deprivation support this notion. One subject in Group 3 (SCT) is a postlingually deafened adult. This individual's data were included because he is an experienced user of tactile aids and there are limited data on the performance of individuals with the Tactaid II.

Table 2 shows the unaided sound field warble tone thresholds for the subjects. Most of the subjects with implants and tactile aids showed no response to sound at the audiometric limits or responded at levels suggestive of vibrotactile sensation. Aided sound field thresholds obtained with conventional hearing aids are shown in Table 3. The subjects with implants and tactile aids showed no aided responses or responded at levels higher than that of conversational speech (i.e., 70 dB SPL). Thus, they were considered to show no benefit from conventional amplification.

Results

Data are presented for those tests administered to all subjects: Change/No Change, MTS (categorization, MTS: C, and identification, MTS: I), Minimal

Table 2

Unaided Sound Field Warble Tone Thresholds (dB SPL) for Subjects

		Frequency (Hz)					
Subject	**Ear**	**250**	**500**	**1000**	**2000**	**3000**	**4000**
Group 1							
SAF	(R)	NR	NR	NR	NR	NR	NR
	L	NR	NR	NR	NR	NR	NR
SAE	(R)	NR	NR	NR	NR	NR	NR
	L	NR	NR	NR	NR	NR	NR
SAG	(L)	126	126	NR	NR	NR	NR
	R	116	126	NR	NR	NR	NR
SAI	(R)	NR	NR	NR	NR	NR	NR
	L	106	111	NR	NR	NR	NR
SCD	(L)	116	NR	NR	NR	NR	NR
	R	116	NR	NR	NR	NR	NR
SBU	(R)	116	NR	NR	NR	NR	NR
	L	121	NR	NR	NR	NR	NR
SAZ	R	115	112	117	NR	NR	NR
	L	110	122	NR	NR	NR	NR
SBI	R	NR	NR	NR	NR	NR	NR
	L	NR	NR	NR	NR	NR	NR
SAR	R	116	107	107	104	115	115
	L	106	97	107	94	100	100
Group 2							
SBE	(R)	126	126	NR	NR	NR	NR
	L	126	116	116	NR	NR	NR
SBR	(R)	121	NR	NR	NR	NR	NR
	L	116	121	NR	NR	NR	NR
SDB	(L)	121	NR	NR	NR	NR	NR
	R	NR	NR	NR	NR	NR	NR
SBJ	(R)	NR	NR	NR	NR	NR	NR
	L	NR	126	NR	NR	NR	NR
Group 3							
SBC	(R)	NR	NR	NR	NR	NR	NR
	L	NR	NR	NR	NR	NR	NR
SBZ	(R)	NR	122	NR	NR	NR	NR
	L	NR	NR	NR	NR	NR	NR
SBT	R	NR	NR	NR	NR	NR	NR
	L	NR	NR	NR	NR	NR	NR
SCT	R	NR	NR	NR	NR	NR	NR
	L	NR	NR	NR	NR	NR	NR

Notes. NR = No response at audiometric limits. Parentheses indicate ear later receiving implant.

Table 3

Aided (Hearing Aids) Warble Tone Thresholds (dB SPL) for Subjects

Subject	Length of Hearing Aid Use	Ear	Frequency (Hz)					
			250	500	1000	2000	3000	4000
	Group 1							
SAF	3-5	(R)	84	104	NR	96	NR	NR
		L	84	104	NR	96	NR	NR
SAE	4-0	(R)	87	98	NR	NR	NR	NR
		L	78	84	NR	NR	NR	NR
SAG	6-9	(L)	79	79	NR	NR	NR	NR
		R	79	85	NR	NR	NR	NR
SAI	7-0	(R)	NR	NR	NR	NR	NR	NR
		L	72	72	77	104	NR	NR
SCD	8-4	(L)	84	NR	NR	NR	NR	NR
		R	86	92	NR	NR	NR	NR
SBU	8-11	(L)	87	89	NR	NR	NR	NR
		R	88	87	NR	NR	NR	NR
SAZ	8-0	L	72	107	NR	NR	NR	NR
		R	78	62	57	101	NR	NR
SBI	6-6	L	91	102	NR	NR	NR	NR
		R	91	102	NR	NR	NR	NR
SAR	2-8	R	65	60	48	55	55	50
		L	60	55	48	50	50	50
	Group 2							
SBE	2-0	(R)	90	101	NR	NR	NR	NR
		L	85	89	100	NR	NR	NR
SBR	2-5	(R)	78	95	NR	NR	NR	NR
		L	73	94	NR	NR	NR	NR
SDB	3-5	(L)	90	100	NR	NR	NR	NR
		R	85	100	NR	NR	NR	NR
SBJ	2-4	(R)	NR	NR	NR	NR	NR	NR
		L	82	82	NR	NR	NR	NR
	Group 3							
SBC	0-9	(R)	NR	NR	NR	NR	NR	NR
		L	NR	NR	NR	NR	NR	NR
SBZ	0-9	(R)	86	95	NR	NR	NR	NR
		L	82	92	NR	NR	NR	NR
SBT	1-0	R	91	97	NR	NR	NR	NR
		L	91	97	NR	NR	NR	NR
SCT	7-2	R	82	NR	NR	NR	NR	NR
		L	82	92	NR	NR	NR	NR

Note. NR = No response at audiometric limits. Parentheses indicate ear later receiving implant.

Pairs, and HAVE (visual, HAVE: V, and word, HAVE: W, scores). The data reported for each subject were obtained during their most recent post-device evaluation which corresponds to the length of device use in Table 1. These data have been analyzed descriptively and interpreted in terms of the trends observed. These comments are not meant to imply statistically significant observations.

Group 1: Subjects with congenital hearing losses. A summary of the results obtained from the subjects in Group 1 appears in Figure 1. Scores have been averaged across subtests on the Change/No Change test and across subjects who use the 3M/House device ($n = 5$) and across Tactaid II users ($n = 2$) on this and all other tests. The subject with the Nucleus device obtained the highest score (i.e., 80%) on the Change/No Change test, whereas the average score of the two subjects with the Tactaid II was the lowest (i.e., 58%). The scores of the hearing aid user and the subjects with the 3M/House device were intermediate to the users of the other two devices.

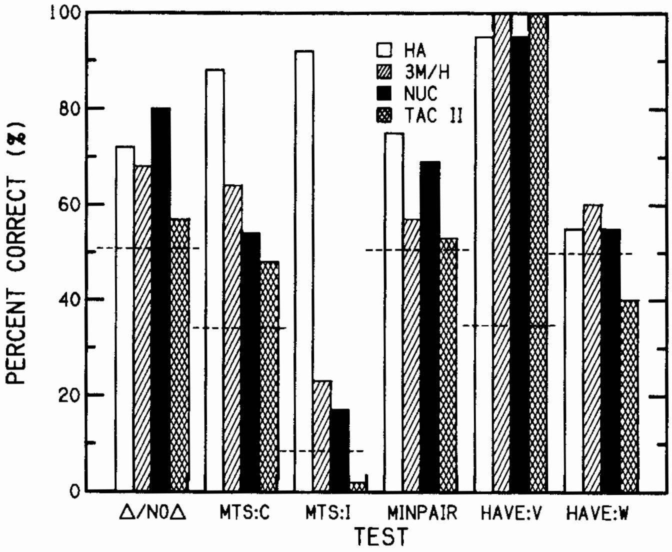

Figure 1. Performance of congenitally hearing-impaired subjects using a hearing aid (HA; $n = 1$), single-channel cochlear implant (3M/H; $n = 5$), multichannel cochlear implant (Nuc; $n = 1$), or tactile aid (Tac II; $n = 2$) on the Change/No Change test, MTS: Categorization (MTS:C), MTS: Identification (MTS:I), Minimal Pairs test (MinPair), and Hoosier Auditory Visual Enhancement test, visual score (HAVE:V) and word score (HAVE:W). Chance performance is indicated by the dashed line.

The results obtained on the MTS:C suggest that all subjects are able to categorize words on the basis of syllable number and stress pattern, but the performance of the hearing aid user was substantially better than that of the subjects who use an implant or the tactile aid. A finding of interest is the lack of superior performance of the subject with the Nucleus device on the MTS:C. The most striking difference between the hearing aid users and the users of the other devices is on the MTS:I. On this measure, the subject with the hearing aid achieved a near perfect score. The implant users could identify some words on the MTS, whereas the subjects with the tactile aid could not. The performance of the hearing aid user and the subject with the Nucleus device was similar on the Minimal Pairs test, and was superior to the performance of the users of either the 3M/House device or the Tactaid II.

All subjects obtained nearly perfect visual scores on the HAVE:V suggesting that they are able to distinguish the homophenous words from the non-homophenous one. Their ability to differentiate words which vary on the basis of phonetic features, as indicated by the word score of the HAVE (HAVE:W), is much poorer, even for the hearing aid user.

Figure 2 shows the data obtained from the subject with the 3M/House implant (SCD) whose performance was superior to that of the other four users of this device. This subject showed evidence of word recognition on the closed-set tasks among which the highest score was achieved on the HAVE:W. Further, near perfect scores were obtained on the measures that did not require word-recognition skills (i.e., Change/No Change and MTS:C).

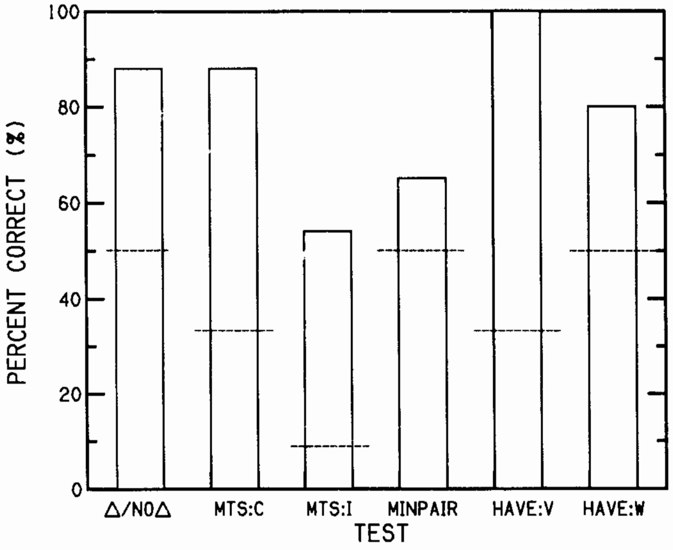

Figure 2. Performance of the highest performer with the 3M/House single-channel implant on the battery of speech perception tests (see Figure 1).

Group 2: Subjects with early acquired hearing losses/short deprivation. Figure 3 shows the data for the four subjects (SBE, SBR, SDB, and SBJ) in this group, all of whom use the 3M/House device. The Change/No Change test was administered to these subjects, but they could not be trained to the task. The subjects' performance was at or below chance on all the auditory-only perception measures. In contrast, they achieved near perfect visual scores on the HAVE:V.

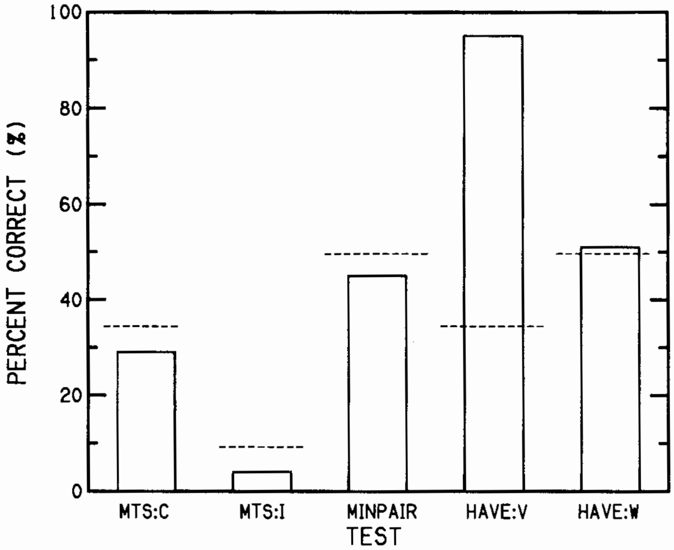

Figure 3. Performance with the 3M/House single-channel implant of four subjects with early acquired hearing losses on the battery of speech perception tests (see Figure 1).

Group 3: Subjects with late acquired hearing loss. Figure 4 summarizes the data for the two subjects with the 3M/House device (SBZ and SBC) who acquired their hearing losses around five years of age. They both achieved high scores on the Change/No Change test, indicating that the single-channel implant provided them with cues adequate to detect certain acoustic changes in speech. Their performance on the MTS:C shows that they were able to categorize words on the basis of syllable number and stress pattern. There is a striking difference in their performance on those tasks that assess word recognition in a closed set. SBZ achieved near perfect scores on the Minimal Pairs test and the HAVE:W, whereas SBC's performance was at chance on these measures. Also, SBZ was able to identify more words correctly on the MTS:I than SBC.

The data for two users of the Tactaid II (SBT and SCT) appear in Figure 5. Recall that SCT is a postlingually deafened adult, whereas SBT lost her hearing at four years of age. SBT achieved scores around chance on all the auditory perception measures except the MTS:C and Change/No Change test. The

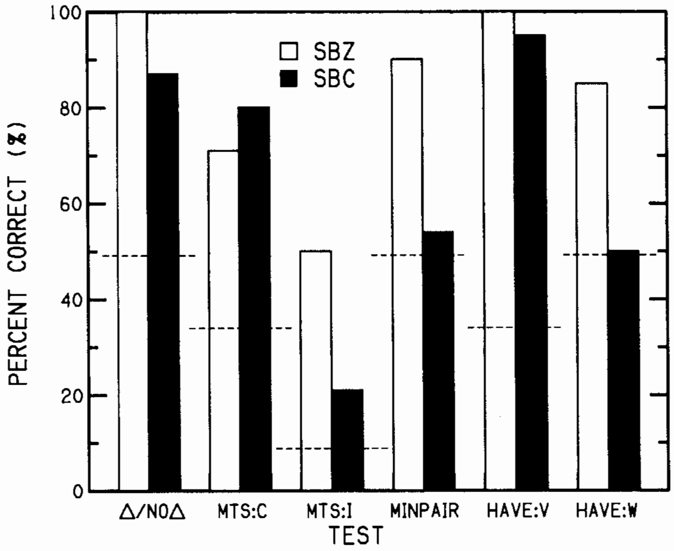

Figure 4. Performance with the 3M/House single-channel implant of two subjects whose deafness occurred at 5 years of age on a battery of speech perception tests (see Figure 1).

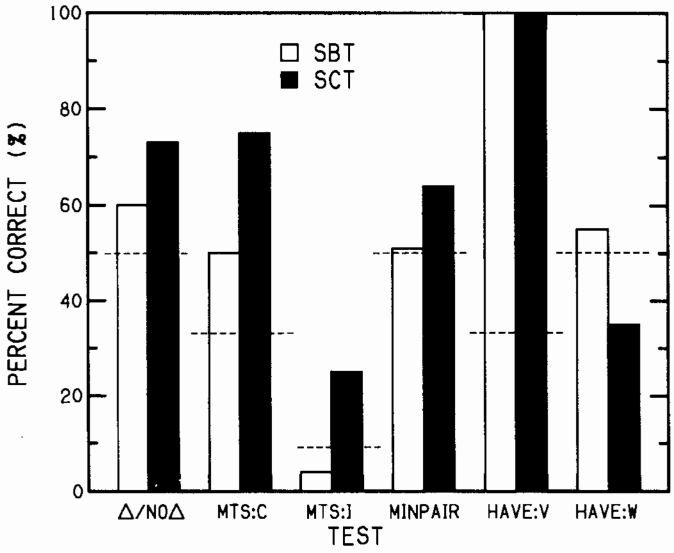

Figure 5. Performance with the Tactaid II of one child who became deaf at 4 years of age (SBT) and one postlingually deafened adult (SCT) on a battery of speech perception measures (see Figure 1).

scores of SCT tended to be higher than those of SBT on all measures except the HAVE. SCT's performance on the MTS:I and Minimal Pairs suggests evidence of limited closed-set word recognition with the Tactaid II.

Discussion

Performance as a function of device type. It was hypothesized that the hearing aid user (SAR) would achieve the highest scores on all the measures. This occurred only for identification of words on the MTS (MTS:I) on which SAR achieved a near perfect score (Figure 1). His score was 40% higher than that of the next highest performer on this measure (SBZ in Figure 4). On the other measures, the scores of one of the single-channel implant users was comparable or superior to that of the hearing aid user. It should be kept in mind, however, that the hearing aid user (SAR) has a congenital hearing loss which was not identified until he was 3½ years old, and he had limited experience with amplification at the time of testing. The implant users who achieved higher scores than SAR had acquired losses.

The next highest level of performance was achieved by the implant users. As a group, the children received the highest scores on those measures that required perception of gross time-intensity changes in speech. This finding is consistent with other data reported for children who use the 3M/House device (Thielemeir et al., 1985). Even though the average performance of the implant users was higher than that of the tactile aid subjects, perfect scores were not achieved by all implant subjects, even on those measures requiring perception of the time-intensity patterns of speech. These large inter-subject differences were typical of the children's performance on all the measures.

One subject, SBZ (Figure 4), achieved high scores on the closed-set word recognition tasks with the single-channel 3M/House device. This is quite remarkable, given the nature of the signal delivered to the user. This child, who lost his hearing at five years of age and received the implant less than one year later, appeared to derive phonetic information from the speech waveform. That this is possible is supported by the data of Van Tasell, Soli, Kirby, and Widin (1987) who found that subjects with normal hearing were able to identify specific phonemes when only waveform information was available.

Exposure to normal aural language for five years is no doubt a contributing factor to SBZ's performance. However, this factor alone cannot account for his superior performance because SBC, who also lost his hearing at age five, did not achieve high scores on the word recognition tests (Figure 4). There are reports that other children who use the 3M/House device are able to perform word identification tasks in an open- as well as closed-set format (Berliner & Eisenberg, 1985). Further, it has been noted that they achieve higher scores than do adult subjects who use the same device. Even though the superior performance of some of the children may not be typical of users of this device, it is crucial that in-depth speech perception evaluations be carried out with these subjects to gain insight into the neural plasticity of the central auditory system.

Another user of the 3M/House device, SCD (Figure 2), also was able to recognize words in a closed set although his performance did not equal that of SBZ. Recall that SCD was placed in the group of congenitally hearing-impaired subjects because of the long period of acoustic deprivation (i.e., 10 years) that he experienced before receiving the implant. His performance on nearly all the perception measures exceeded that of the other subjects in Group 1, even the user of the multichannel implant (Figure 1). It appears that for this individual the advantages of some period of normal hearing outweighed the disadvantages of the long period of auditory deprivation in performing the tasks under study.

The performance of the subject with the Nucleus 22-Channel Cochlear Implant System is encouraging, given the brief time that she has used the device and the fact that her loss is congenital. Her scores, however, are far from perfect on the word recognition measures. Further, her ability to integrate auditory and visual information is poor. These findings illustrate the need for long-term training and experience, even with the most sophisticated device.

The subjects who achieved the lowest scores were the three users of the Tactaid II (Figures 1 and 5). Unlike the group of implant users, who demonstrated large individual differences on all the measures, the performance of all the children who used tactile aids was uniformly poor. Their highest level of performance was on the Change/No Change and MTS:C tests with low scores obtained on all other procedures. These findings should be interpreted with caution because of the limited number of children who have been evaluated with the device.

The children with tactile aids demonstrated poor performance on the categorization portion of the MTS as well. This finding is in agreement with the results of Carney and Bechler (1986) who reported poor categorization of stress pattern and syllable number using multi-channel tactile aids. If, for example, a monosyllabic word is composed of phonetic segments with both low- and high-frequency components (e.g., "wash"), then both channels of the Tactaid II are stimulated in sequence, and the child thinks that a two-syllable rather than one-syllable word has been produced. In contrast, a multisyllabic word (e.g., "animal") may feel like a monosyllabic word because all the sounds are continuant and within the frequency region of one channel.

A finding of interest is the superior performance of the postlingually deafened adult with the Tactaid II (Figure 5). His knowledge of the language evidently permitted him to develop strategies to decode and encode the vibratory patterns in a meaningful way. Perhaps because of their severe language deficits, the children were less able to do this, including SBT who lost her hearing at 4 years of age. The difference between the adult and children on the perception measures illustrates the danger in generalizing performance results obtained with adults (postlingually deafened or normal hearing) to young deaf children.

Performance as a function of age at onset of deafness. The findings are difficult to interpret with respect to age at onset of deafness because of other confounding variables. Two implant users with a late onset of deafness (SBZ and SBC, Figure 4) demonstrated marked differences in their perceptual performance. One subject in Group 1 who had an acquired loss but a long period of deprivation (SCD, Figure 2) achieved higher scores than the subjects in Group 2 whose onset of loss was at a similar age but who had experienced short periods of auditory deprivation (Figure 3). These subjects were younger and had used their devices a shorter period of time than did SCD and some of the other subjects in Group 1. A larger number of subjects is needed to sort out the effect on performance of variables such as age at onset of deafness, chronological age, length of deprivation, and communication methodology.

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