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A comparison between patients using cochlear implants and hearing aids. Part I: Results on speech tests

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A comparison between patients using cochlear implants and hearing aids.

Part I: Results on speech tests

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Abstract

The speech perception ability reported from profoundly hearing-impaired persons using hearing aids or cochlear implants varies widely. A test battery was constructed that consisted of segmental and suprasegmental tasks and connected speech presented in three different modalities: visual (V), auditive (A) and audio-visual (AV). Two groups of patients participated. Fifteen subjects with a profound hearing loss (PTA 89.4 dB) used hearing aids (HA) and fifteen subjects used cochlear implants (CI), either a single-channel extracochlear implant, or a multi-channel intracochlear implant. The results obtained from the speech reception data showed a great variation among the subjects. In the Connected Discourse Tracking test (CDT),without support of lipreading, the HA-group received a higher mean benefit from their conventional hearing aid compared to the mean for the CI-group. Many of the cochlear implantees obtained great benefit from their aids, but others derived little benefit.

Introduction

During the last 15 years cochlear implants have made an enormous impact on the life of many profoundly deaf persons. Cochlear implants have also resulted in an increased general interest in methods for the rehabilitation of profoundly hearing-impaired patients in many other ways.

A difficult problem is that published results show a wide variation in performance with the same type of cochlear implant, and the possibilities to predict these results from preoperative data and measurements are limited (Tyler, 1991; Dorman, 1993; Dowell, 1995). Many persons derive great benefit from their aids in their daily life and many, when tested, were found to have some open-set speech understanding. On the other hand, others have little benefit and performed less well especially on more difficult speech perception tests.

A variety of factors may have an effect on the benefit received from a cochlear implant. These factors may include the duration of time a person has been deaf, the number of functioning nerve fibres in the hearing nerve, the person´s motivation, etc. There are no definitive tests to estimate the expected degree of benefit which can be administered prior to implantation.

Relatively few comparative studies have been made of adult hearing-aid users by applying the same type of speech reception tests that have been used for the evaluation of the results obtained with cochlear implants (Rihkanen et al., 1990; Spillman & Dillier, 1990; Agelfors, 1994).

Cochlear implants were only seen from the beginning as an alternative technical aid for profoundly (or totally) deafened adults unable to derive any benefit from a conventional hearing aid. The cochlear implant research groups rarely give any details about their selection criteria but it is apparent that the good results obtained with multi-channel systems have resulted in a shift of the selection criteria. During the last years, many researchers and clinicians have hypothesised that severe-to-profoundly hearing-impaired adults, who benefit only marginally from hearing aids, might also be cochlear implant candidates.

Thornton (1986) estimated the number of patients who might be potential candidates for cochlear implantation. It is clear from his study that the number of totally deaf patients is much smaller than the number of patients that have some useful residual hearing. Which of these severely hearing-impaired persons that are candidates for a cochlear implant and which are likely to derive more benefit from a properly fitted conventional hearing aid or a future auditory recoding hearing aid – this is an important question.

The aim of this study was to obtain some insight into these questions by comparing test results from a group of long-accustomed hearing-aid users with a group of cochlear implant users. Testing was made in three sensory conditions: visual information only, visual information combined with auditory signals (audiovisual), and auditory signal alone with assistive device.

Method

Subjects

Two groups of deafened or hearing-impaired adults with a severe to profound hearing loss formed the basis of the study. One group consisted of 15 cochlear implant users, all deafened adults, who had received limited benefit from a conventional hearing aid before receiving a cochlear implant. In the other group, 15 hearing-aid users participated, all with long experience with hearing aids. The subjects all came from the Stockholm area. All subjects participated voluntarily in the study.

Cochlear implants have been used in Sweden for twelve years and nearly 150 patients have been implanted. From the beginning, a single-channel extra-cochlear, Vienna/3M, implant was used, but today multichannel cochlear implants are preferred.

1) Cochlear-implant group (CI)

All subjects had at least six months of experience with their implant and all but one (CI:6) were implanted at Södersjukhuset (Söder Hospital) in Stockholm and have followed the rehabilitation programme at the hospital. The experience of cochlear implant use for the group was 2.6 years on average and ranged from 6 months up to 6 years. Two subjects were implanted with a single-channel, extracochlear implant, Vienna/3M (Hochmair-Desoyer et al., 1981). Thirteen subjects were implanted with a multi-channel intracochlear implant. Eleven used the Nucleus device (Clark et al., 1981) and two used the Ineraid device (Eddington, 1980). The most important difference between the two processors, Nucleus and Ineraid, is that the Nucleus design is a nonsimultaneous, pulsatile 21-channel feature extraction device, whereas the Ineraid processor is a simultaneous, analog four-channel implant. The latter does not perform feature extractions but presents the broadband speech waveform in four filter channels (Dorman et al., 1990).

Fourteen subjects used their implant daily but one subject used his implant only sporadically (CI:3), as he derived limited benefit from the implant in communication situations. The subjects, seven females and eight males, ranged in age from 35 to 80 with a mean age of 59.3 years (SD 12.6). In tables 1 and 2, individual data for the CI-users are given.

2) Hearing-aid group (HA)

Fifteen experienced hearing-aid users participated, all with a severe to profound hearing loss. The pure-tone average for the better ear of the group was 89.1 dB, ISO (SD 15.2) and the average duration of hearing-aid-use was 25.5 years (SD 8.6). The subjects, eleven females and four males, ranged in age from 38 to 74 with a mean age of 59.3 years (SD 10.6). Some subjects derived good benefit from the hearing aid, others derived poor benefit. All subjects but one (HA:8) were using the aid all day. This particular subject was an excellent lipreader but suffered from a very poor dynamic range which caused discomfort. All subjects were tested with their hearing aid adjusted to the most comfortable listening level. In tables 3 and 4, individual data for the HA-users are given.

Test material

The test battery consisted of two parts: speech perception tests and self-rating performance inventory (PIPSL), see Part II. The speech tests consisted of a segmental test, a test of prosodic contrasts and a Connected Discourse Tracking test (CDT), well-known as speech tracking technique. The same speaker was used in all test situations.

Speech tests

1) Inter-vocalic consonants

The segmental test consisted of sixteen /aCa/-syllables preceded by a carrier phrase. The consonants were chosen to sample a variety of distinctions in voicing, place of articulation, and manner of articulation. The following Swedish consonant phonemes were presented: /p, b, m, t, d, n, k, g, ŋ, f, v, s, ʃ, r, l, j/. The consonant test consisted of four repetitions of each of the sixteen consonants in a random order. The list was videorecorded and presented on a TV-screen. The subjects were tested at their most comfortable level, adjusted by themselves, in test situations audiovisual and audition alone with assistive device. In visual presentation, the loudspeaker was switched off.

Table 1. Some data of the cochlear implant subjects

Subject	Sex	Age	Implant	Years of deafness before impl.	Years with implant	Etiology
CI:1	F	35	Vienna/3M	3	6	Unknown
CI:2	M	47	Vienna/3M	20	5	Skull fracture
CI:3	M	60	Nucleus/F0F1F2	37	2	Ototoxicity
CI:4	M	66	Nucleus/F0F1F2	14	2	Sarkoidos
CI:5	F	46	Nucleus/MPeak	1.5	0.7	Unknown
CI:6	F	40	Nucleus/F0F1F2	20	1	Unknown
CI:7	F	62	Nucleus/Mpeak	8	3	Unknown
CI:8	F	62	Nucleus/MPeak	9	1	Unknown
CI:9	F	58	Nucleus/MPeak	2	2	Unknown
CI:10	M	67	Nucleus/MPeak	6		Otosclerosis
CI:11	F	57	Nucleus/MPeak	6	3	Unknown
CI:12	M	68	Nucleus/MPeak	21	5	Otosclerosis
CI:13	M	74	Nucleus/Spectra	10	0.6	Unknown
CI:14	M	68	Ineraid	5	2	Unknown
CI:15	M	80	Ineraid	2	2	Unknown

Table 2. Audiometric thresholds (preop.) in dB HL of the implanted ear for the cochlear implant subjects. "NR" means that no response was obtained at 125 dB HL at 500, 1000 and 2000 Hz.

Subject	Frequency					PTA
	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
CI:1	100	110	110	105	NR	108
CI:2	105	120	125	NR	NR	123
CI:3	120	110	105	115	110	110
CI:4	110	105	120	120	NR	115
CI:5	90	90	110	115	115	105
CI:6	105	NR	NR	NR	NR	125
CI:7	NR	120	NR	NR	NR	123
CI:8	NR	NR	110	115	NR	116
CI:9	85	95	95	85	100	92
CI:10	105	120	NR	NR	NR	123
CI:11	110	115	120	120	NR	118
CI:12	105	120	115	100	90	112
CI:13	100	100	110	NR	NR	112
CI:14	NR	NR	NR	NR	NR	125
CI:15	NR	NR	NR	NR	NR	125

An information transmission analysis (Miller & Nicely, 1955) was performed on each subject´s consonant confusion matrix for each test condition. This analysis calculates the information received by the subject as a percentage of the information present in the stimulus set. It takes into account both the distribution of the features in the test materials and the number of values that are permissible for each feature. Consonants were classified according to five articulatory features: voicing, stop, nasality, frication, and place. For the place feature, the consonants were categorised according to whether they are produced in the front, middle or back of the vocal tract.

Table 3. Some data of the hearing-aid subjects

Subject	Sex	Age	Type of HA	Aided ear	Years of HA-use	Etiology
HA:1	M	38	Oticon E38 P	bin	28	Unknown
HA:2	F	56	Widex G1	bin	30	Familial
HA:3	M	43	Oticon E24	right	25	Meningitis
HA:4	F	47	Widex G2	bin	30	Unknown
HA:5	M	68	Philips S46-0	bin	30	Noise exposure
HA:6	F	71	Widex G2	bin	35	Unknown
HA:7	F	74	Siemens 264	right	18	Autoim. Disease
HA:8	F	50	Widex ES1	bin	30	Trauma
HA:9	F	66	Danavox Genius	right	30	Ototoxicity
HA:10	M	62	Philips S1594	left	13	Familial
HA:11	F	60	Oticon E38 P	right	16	Unknown
HA:12	F	62	Philips S46-0	bin	15	Unknown
HA:13	F	61	Oticon E39	bin	40	Unknown
HA:14	F	69	Widex G2	bin	30	Familial
HA:15	F	63	Eurion	right	12	Unknown

Table 4. Audiometric threshold, dB HL, of the better ear for the hearing-aid subjects. "NR" means that no response was obtained at 125 dB HL, at 500, 1000 and 2000 Hz.

Subject	Frequency					PTA
	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
HA:1	85	100	100	95	105	98.3
HA:2	65	65	70	115	95	83.3
HA:3	50	55	65	90	100	70.0
HA:4	70	100	105	NR	NR	110.0
HA:5	45	50	65	85	95	66.7
HA:6	60	80	105	120	NR	102.2
HA:7	55	45	70	75	85	63.3
HA:8	60	60	80	100	100	80.0
HA:9	70	70	90	120	120	93.3
HA:10	90	75	80	80	90	78.3
HA:11	NR	115	110	100	90	108.3
HA:12	80	90	105	105	105	100.0
HA:13	100	110	115	120	120	115.0
HA:14	90	95	85	65	65	81.7
HA:15	60	75	90	90	90	85.0

2) Suprasegmental test

The specific prosodic features tested were: number of syllables (one- and two-syllable or two- and three-syllable words), vowel length (long and short vowels), juncture, tone (difference between the Swedish accent one and accent two), and word emphasis in sentences. The test words were preceded by a carrier phrase, and the prosodic contrasts were presented as a two-alternative forced-choice task. In all tests, response alternatives were used that differed with respect to the tested contrast only. Two test lists were created and recorded on video and presented at most comfortable level, adjusted by subjects, in test situations audiovisual and audition alone with assistive device. In test situation vision alone the loudspeaker was switched off.

3) Speech-tracking or Connected Discourse Tracking (CDT)

The tracking technique developed by De Filippo and Scott (1978) has been used by many groups to train and to evaluate the reception of connected speech via lipreading alone and in combination with various types of sensory aids. The speaker reads from a book, phrase by phrase, and the speech-reader (the subject) is required to repeat the text verbatim. If the phrase is not correctly repeated, the speaker employs a hierarchy of strategies to assist the subject in repeating every word correctly. The score is calculated according to the number of words in the text conveyed in a given time.

Today, CDT is probably the most popular and most widely applied speech perception test at the connected text level. Its popularity can be explained by the fact that it imitates everyday communication and is easy to administer. However, the results obtained in a speech-tracking test are affected by several factors of which the most important are the text complexity, the speech rate of the speakers, and the type of help strategy used (Spens, 1995). Tye-Murray & Tyler (1988) analysed some of these factors and came to the conclusion "that tracking should not be used in across-subject test designs. It is inappropriate for comparing aural rehabilitation strategies, communication devices, or presentation modes." We were aware of the importance of the critique advanced by these authors and tried to minimise uncontrolled factors by letting all testing be made by the same person (the author) and by using a simple and well-defined strategy. The following method was used:

1. The speaker reads a whole sentence or phrase.
2. If the subject was unable to repeat the phrase correctly it was broken into smaller units of two–four words which were read one by one.
3. If a unit was not repeated correctly, it was read again.
4. If the subject was still unable to repeat the unit correctly, it was given in writing.

The speech material chosen had a relatively consistent level of reading difficulty from session to session. During each test session, tracking was performed for a total of ten minutes under each of the conditions: lipreading plus aid, lipreading alone and, auditory alone with the device. All subjects were tested in condition auditory alone but testing was interrupted as soon it was evident that this situation was too difficult. The CDT-test was presented live by the same speaker as in the vCv-test and suprasegmental test. The tracking rate achieved by a normal-hearing subject who used the same method with the same speaker and the same text material was 88 words per minute.

Statistical procedures

Pearson product-moment correlations were used to analyse the associations with other measures used. Student´s t-test (unequal variance) was used to evaluate between group differences, and t-test for paired sample was used within the groups but between test conditions.

Results and discussion

The mean scores and standard deviations obtained for the two groups of subjects on different speech tests in the three test conditions are presented in table 5. Statistical analysis showed that there was a significant difference ($p<0.05$) between the two groups of subjects on the prosody and CDT-test with an advantage to the hearing-aid users in test situation auditory alone with assistive device. There was no statistically significant difference in test situation lipreading alone between the groups of subjects. Note that the subjects performed similarly on the vCv-syllable test in all three conditions. There was, however, a significant improvement of the average score on speech tests in the combined situation, compared to lipreading alone, for both groups of subjects. The greatest improvement with the aid (AV) was on the Connected Discourse Tracking test (CDT). The enhancement was in mean around 30 words per minute for both groups. For the consonants and connected speech the means for AV were significantly greater ($p<0.001$) than the means for conditions auditive and visual alone. For prosody, the means for AV-condition were significantly greater than the means for visual condition ($p<0.001$), but there were not any statistical differences between the means for conditions auditive alone and audiovisual.

There were, however, large variations within the groups and in the following these variations are analysed.

Table 5. Mean scores (standard deviations are given in parentheses) obtained for the two groups of subjects, HA- and CI-users, on speech perception tests in three different conditions: visual only (V), audiovisual (AV) and auditory only (A) with assistive device. Figures in bold show a significant difference between the groups (p=<0.05).

	Visual		**Audiovisual**		**Auditive**	
	CI	**HA**	**CI**	**HA**	**CI**	**HA**
vCv, % transmitted information	63.6 *(5.9)*	62.9 *(4.9)*	80.9 *(10.1)*	87.1 *(9.1)*	60.0 *(10.1)*	64.8 *(10.5)*
Prosody, % correct chance level = 50%	75.4 *(7.3)*	78.2 *(9.2)*	**85.2** *(6.2)*	**91.5** *(9.6)*	**81.8** *(9.8)*	**90.4** *(9.1)*
CDT words per minute	24.0 *(8.7)*	23.2 *(12.3)*	54.1 *(14.4)*	60.5 *(17.7)*	**18.6** *(17.3)*	**32.6** *(22.6)*

Prosody

Results obtained from the prosody test are presented in figures 1-3. The statistical analysis in table 5 shows a significant difference between the two groups in test situation audiovisual and auditory alone for the suprasegmental test. When analysing the specific prosodic contrasts in test condition, audition alone with respective aid, there was a statistical difference in mean value between the two groups for the prosodic contrasts: vowel length ($p<0.01$) and juncture ($p<0.05$), shown in figure 1. The hearing-aid users scored around 90% correct in this test situation compared to the cochlear-implant users, who scored around 75% correct. There were no statistical differences in mean values between the two groups regarding the prosodic contrasts emphasis and tone which are pitch and intensity related contrasts. Both groups of subjects obtained an improvement in the audiovisual situation compared to the lip-reading alone.

Figure 2 shows the mean value for the four word-pairs in the test list that measured the ability to identify vowel length. The presentation mode was auditory only and all subjects scored above chance-level (50%). There was no problem for the subjects to discriminate between the mono-syllabic word-pair [vo:t/vɔt], as a distinct difference in vowel length occurs when the vowel is followed by a voiceless stop in final position. The HA-users scored 100% correct irrespective of degree of hearing loss. On the other hand, there was a significant difference in mean value between the two groups for the word-pair [vi:la/vɪla] ($p<0.01$) and [ti:ga/tɪga] ($p<0.05$), in which the target vowel was followed by a voiced consonantal feature. Many of the subjects especially in the CI-group had difficulties in discriminating between these word-pairs. This can probably be explained by a poor spectral resolution in the high-frequency domain

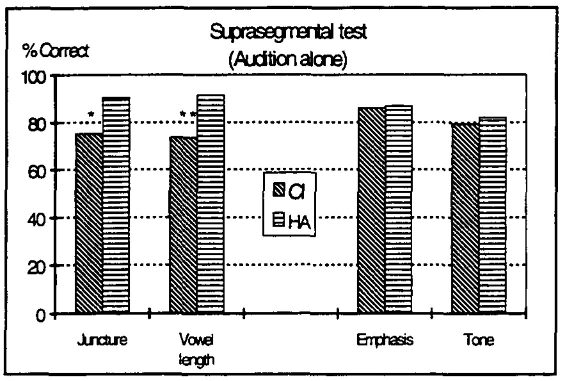


*Fig. 1. Mean score obtained by each group of subjects on the prosodic test, presented auditory alone with assistive device. Chance-level is 50% correct. *(p<0.05), ** (p<0.01)*

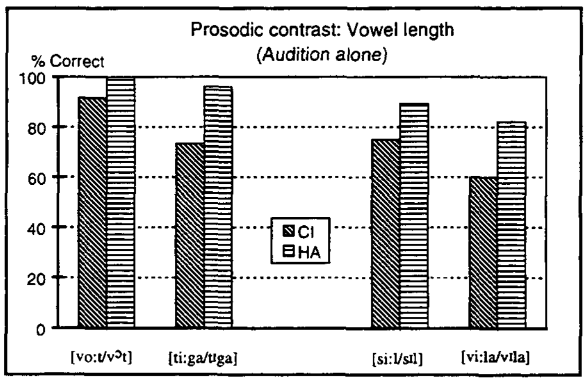


Fig. 2. Mean score obtained by each group of subjects on the prosodic contrast "vowel length", presented auditory alone with assistive device. Chance-level is 50% correct.

(F2/F3). This results in difficulties to detect boundaries between the phonemes. Confusions between vowel length in [ti:ga/tIga] might be explained by a poorer temporal resolution for many of the CI-users.

Figure 3 shows the mean score for two word-pairs which differ in the prosodic contrast juncture (En sjuk_ gymnast/ En sjukgymnast) and (Erik stack/ Eriks tack) obtained by the two groups of subjects. There is a significant difference ($p<0.05$) between the groups for the test words (En sjuk gymnast/ En sjukgymnast). The HA-users seemed to have no problem in discriminating between these words, while many CI-users have difficulties in detecting the differences. This might also be explained by poor time resolution.

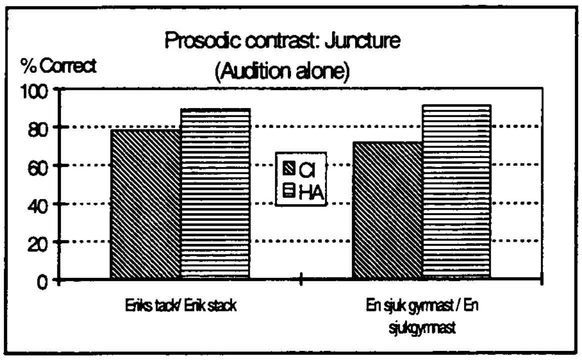


Fig. 3. Mean score obtained by each group of subjects on the prosodic contrast "juncture" presented auditory alone with assistive device. Chance-level is 50% correct.

Connected Discourse Tracking (CDT)

Mean recognition scores on the CDT-test in the three different situations showed no significant difference between the groups in visual and audiovisual presentations but a significant difference in presentation auditory alone, see Table 5. However, there was a large variation in performance within the groups, especially in test situation audition alone with the assistive device. It is well known that there are large differences in levels of performance of all CI-users, regardless of the type of implant, years of experience, etc.

In Figure 4 is shown the relation between CDT, auditory alone with hearing-aid and degree of hearing loss, PTA at 500, 1000 and 2000 Hz. There was a correlation –0.8 between these tests, but the correlations among test scores must be regarded with caution, because the size of the population sample in this study was small.

Based on our experiences, a score around 30 to 40 words/min. represents acceptable communication. This score is obtained by the hearing-aid users with a hearing loss less than 85–95 dB (PTA). However, two subjects (HA:1 and HA:4) scored around 40 words per minute in spite of a profound hearing loss around 100 dB HL. Their relatively good performance could perhaps be explained by an unknown conductive component in their hearing loss. Another hypothesis is that these two subjects started their hearing-aid use in early youth which means that they have around 30 years of experience in hearing-aid use. Their better

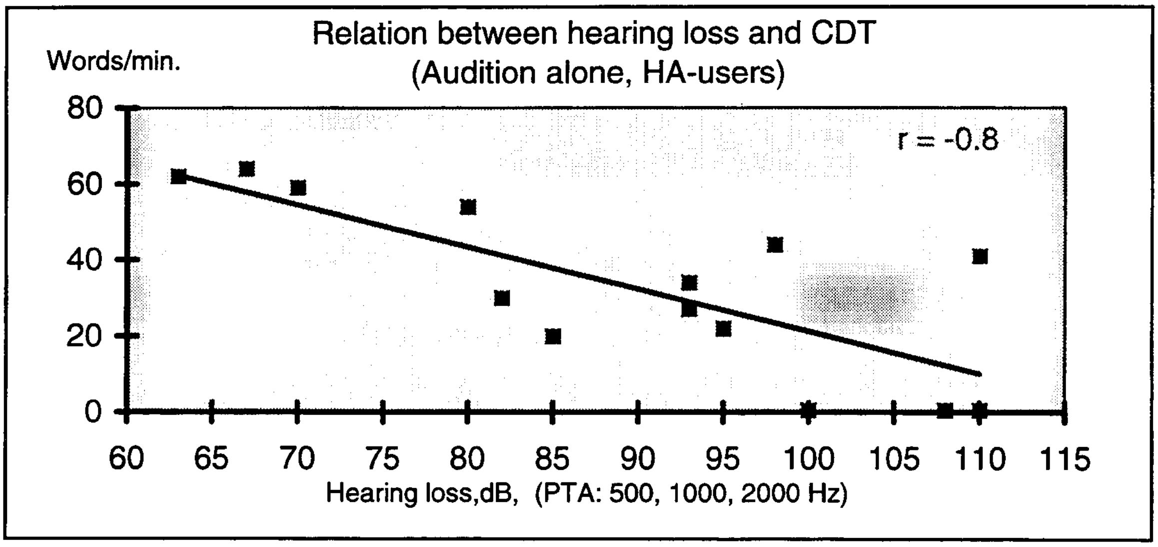


Fig. 4. Individual relation between Connected Discourse Tracking test (CDT), auditory alone with hearing aid, and degree of hearing loss for the best aided ear.

performance in perceiving running speech could perhaps also be age-related as both of them are younger than the other subjects with a profound hearing loss, as can be seen in Table 3. Three of the subjects (HA:11, HA:12 and HA:13) with a hearing loss ≥100 dB (PTA) were not able to perceive speech auditory alone on the CDT-test.

Individual results obtained from the same test (CDT) presented in situations visual and audiovisual are shown in Figure 5. Scores above the diagonal line indicate an improvement with the aid, and all subjects but one (CI:9) obtained some improvements with their aids in this particular speech test. However, some subjects, hearing-aid users as well as cochlear implantees, obtained poor benefit from their aids. If they are poor lipreaders as well, they have severe problems in daily communication situations. Four subjects are excellent lipreaders, tracking at more than 40 words per minute, lipreading alone. Results for many subjects were around 70–80 words per minute which indicate very good communication ability, i.e., only few repetitions, and that they are able to communicate nearly as well as normal-hearing persons in this particular test situation.

To obtain more information about the difference in performance, the HA/CI-users were divided into two groups based on their ability to perceive speech auditory alone on the CDT-test, see Fig. 4 and Fig. 6. Subjects who obtained a result of more than 20 words/min., are labelled HA/CI(+), the others HA/CI(–). One of our single-channel implanted subjects (Vienna) performed at higher level than some subjects using multi-channel implants (Nucleus/Ineraid) but in general for adults with acquired deafness a multi-channel implant is superior to single-channel implant, especially in speech understanding auditory alone without any support of lipreading (Gantz et al., 1987; Cohen et al., 1993).

Figure 7 shows the correlation and trendline between individual results on % transferred information of consonant recognition auditory alone for the two groups of subjects and the speech tracking score on the CDT-test. There was a high correlation for the HA-group, 0.89, and the correlation for the CI-group was 0.69. Other high correlations between running speech and consonantal features in condition auditory alone (A) were for the HA-group: place 0.81 and frication 0.75. The place feature (A) was also correlated to their hearing loss (PTA) r = –0.83. For the CI-group, the correlations between running speech and consonantal features had almost the same features as for the HA-group but with a weaker correlation at around 0.6, except for the nasality feature which showed no significant correlation at all.

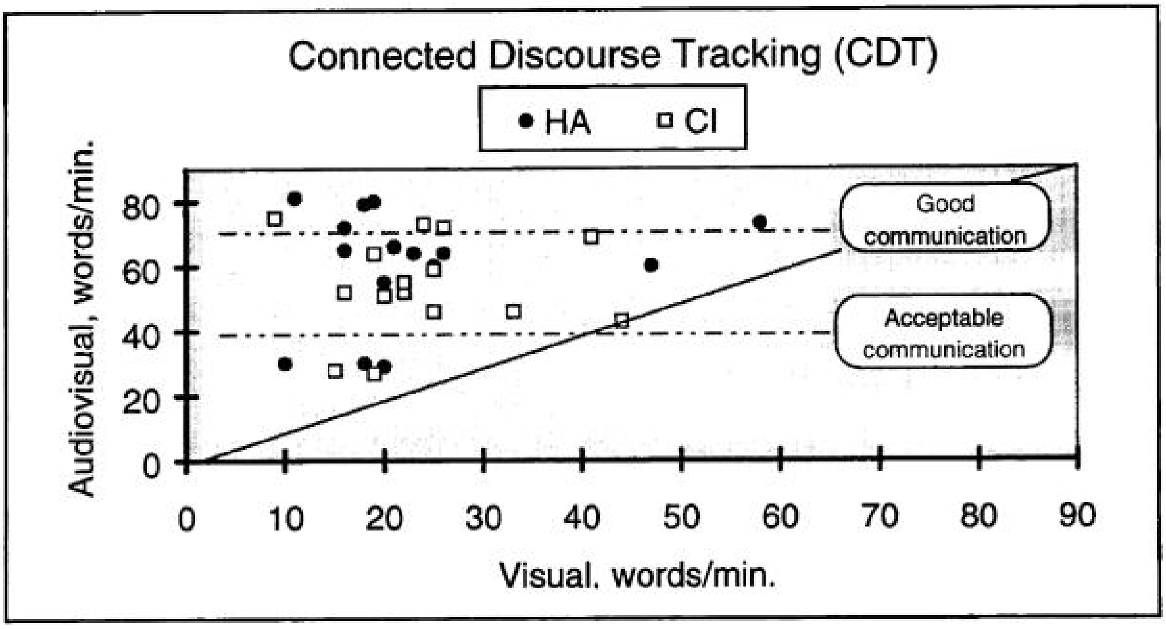


Fig. 5. Individual performance obtained by HA/CI-users on CDT in two situations, vision only and vision plus aid.

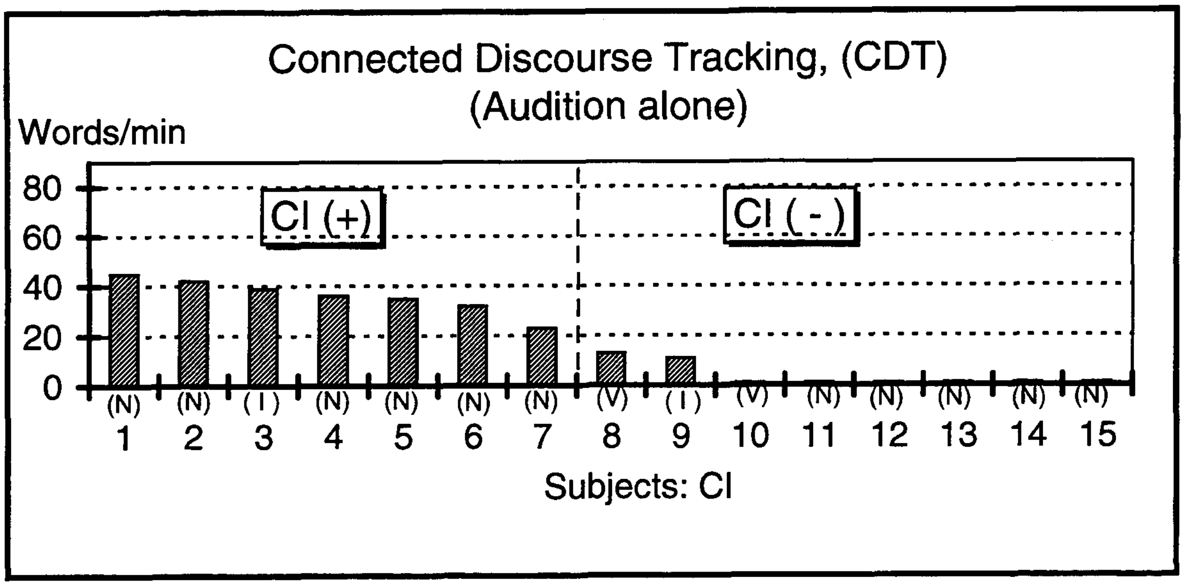


Fig. 6. Individual results obtained from the cochlear implant subjects on Connected Discourse Tracking test, auditory alone. (N = Nucleus, I = Ineraid, V = 3M/Vienna).

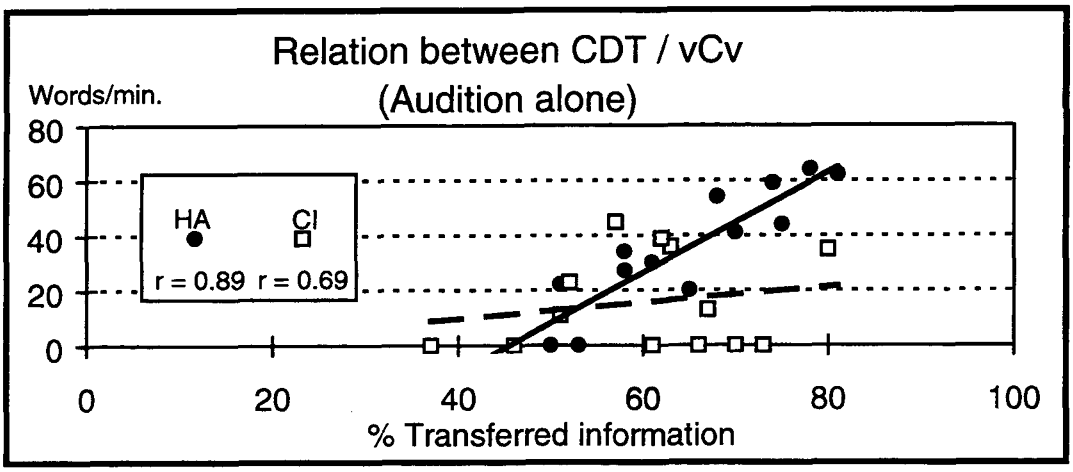


Fig. 7. Correlation between individual results on Connected Discourse Tracking and vCv-syllables in condition auditory alone with assistive device for the HA/CI-subjects.

Segmental test

Consonant confusion matrices for the four groups of subjects are shown in Figure 8. Based on these matrices an information transfer measure was calculated for each feature in the three conditions.

The confusion matrices, Figure 8, were analysed to obtain detailed information about some error responses from the different groups of subjects. Manner was very well recognised especially by the HA(+)-group. The fricatives [f, ʃ, s] were confused with each other and for many of the poor HA/CI-subjects heard as [t/k], and vice versa. This can be explained by a profound hearing loss in high-frequency domain for the HA-users and that the CI-users with a poor performance received little information from higher frequencies. The good performers (CI+) heard the intense fricative [s] predominantly as [f /ʃ] and it was never confused with voiceless stops. However, the recognition of [s] was poorly perceived by all four groups of subjects: 18%, 16% (CI-users) and 30%, 8% (HA-users) correct. The fricative [ʃ]-sound was best perceived by the CI-users, 96% and 63% correct compared to the HA-users 48% and 17%

correct. Manner errors for nasals were confused with other voiced consonants, but the nasals were heard predominantly as the [l]-sound or as other voiced consonants sharing the same characteristics like high amplitude and a low-frequency onset. The identification of place varied with manner and was poorly perceived by almost all subjects in the study.

In the following, a comparison is made of some of the results between the different groups.

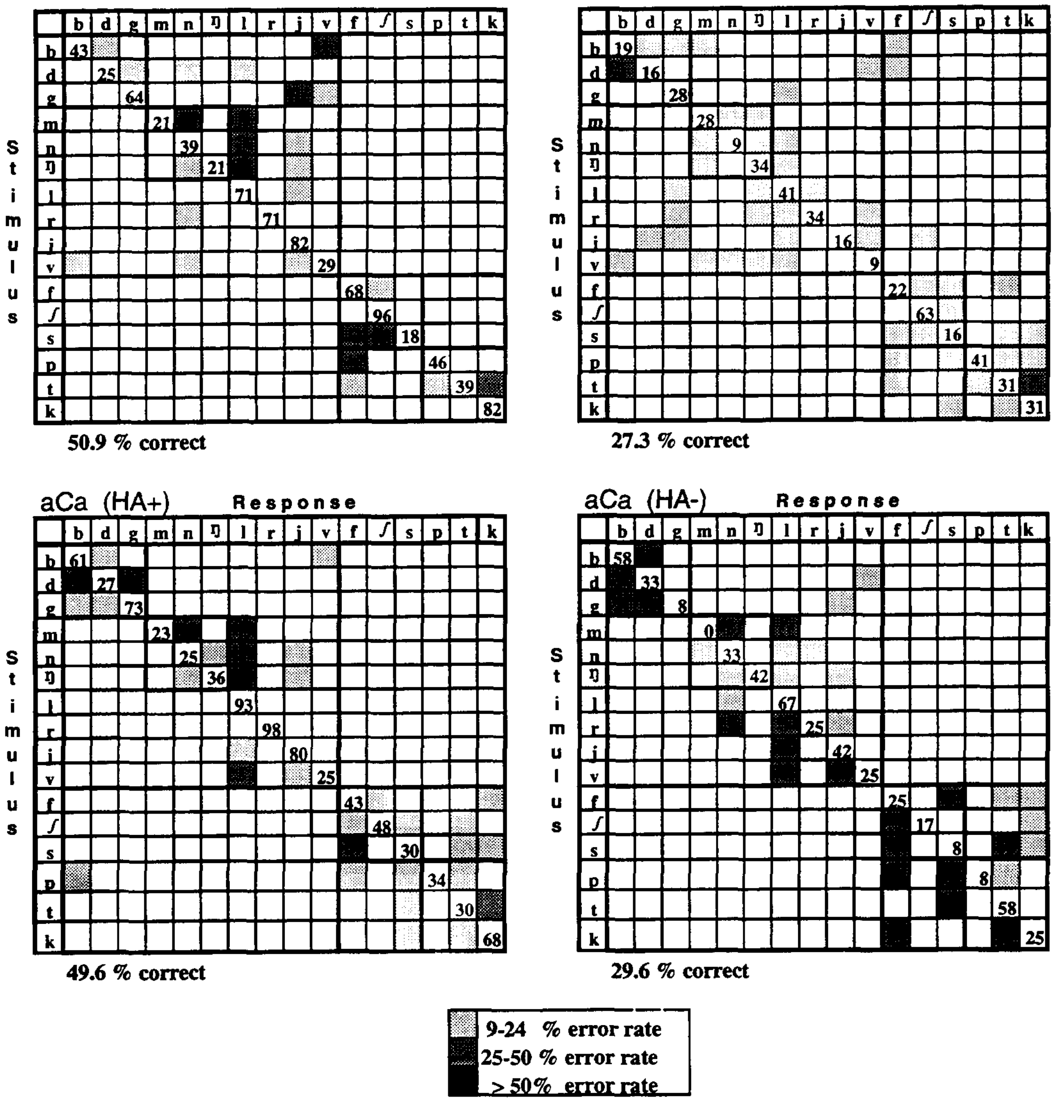


Fig. 8. Confusion matrices from consonants (vCv) in condition auditory alone (A) for four groups of subjects, HA(+/–) and CI(+/–) users. Percent error response indicates by filled squares (9–100%). Confusions less than 9% are not shown in the matrices. Shading indicates manner and voicing categories.

Better subjects: HA vs CI

The average score obtained by the better performing HA-users and CI-users was very similar, 49.6% and 50.9% correct, respectively. However, there are some noticeable differences. The manner feature is perceived better by the HA-group except for the voiceless fricatives that are perceived as voiceless stops. The cochlear implantees are better to identify the to fricative [ʃ], but the explanation for this seems be that they perceive all high-energy fricatives as [ʃ].

Poorer subjects : HA(–) vs CI(–)

For the vCv-syllables, auditory alone, the average score obtained by the poorer HA-users was 29.6% and 27.3% correct for the CI-users. The poorer cochlear implantees are better to identify the fricative [ʃ] (63%) compared to the poorer HA-users (17% correct), see above. The error responses were divided between other signals with fricative energy, heard as [f] by the poorer HA-users and heard as [s] by the poorer CI-users. The HA-subjects had greater difficulties of perceiving the distinction voiceless fricative and voiceless stop. For the voiced stops [b,d,g], errors were limited to [b,d], especially by the HA-group, and the voiceless [p]-sound was mostly heard as [f,s].

CI-subjects: CI(+) vs CI(–)

The largest differences between the better and poorer subjects were for the consonants [j] 66%, [k] 51%, [f] 46% and [g] 36%. Voiced/voiceless distinction was very well perceived by the better subjects. The velar stops [k,g] are the best perceived among the stop consonants by the better subjects. This may be explained by a better frequency resolution in the mid-frequency range. The poorer subjects CI(–) had more spread error responses.

HA-subjects: HA(+) vs HA(–)

The largest differences between the better and poorer subjects using hearing aids were for the consonants [r] 75%, [g] 65%, [k] 43%, [j] 42% and [ʃ] 31%. The [r]-sound was the best recognised consonant by the HA(+)-group (98%) and was never confused with other phonemes. The velar stops were well perceived by the HA(+)-group compared to the poorer hearing-aid users.

Transmitted information

The average percentages of transmitted information obtained are presented as histograms for five articulatory features: voicing, stop, frication, nasality and place (Figures 9, 10, and 11). A comparison was made for each feature using *t-tests* for paired samples.

Average percentages of information transmitted in the audio-visual (AV) condition was significantly greater ($p<0.05$) than for visual (V) condition for all groups and for every feature with two exceptions, place and frication. For the cochlear implantees CI(+) and CI(–), the nasality feature was most difficult to perceive in the AV-condition but the AV was, however, significantly greater ($p<0.05$) than for auditory alone (A) for this feature. The better hearing-aid users had less difficulties with this feature.

All groups of subjects showed that AV was not significantly greater than A for the voicing consonants feature. The voice feature is difficult to see as it is produced by vocal cord vibrations but was perceived well in the AV-situation by almost all subjects except for some subjects in the CI(–)-group. Notice that the poorer hearing-aid users were able to detect voice/voiceless information, auditory alone, at around 78% correct transmitted information.

The place feature was in the AV-condition not significantly better transmitted than in the V-condition, which shows the difficulty to perceive information about place auditory alone, both for the CI- and HA-users.

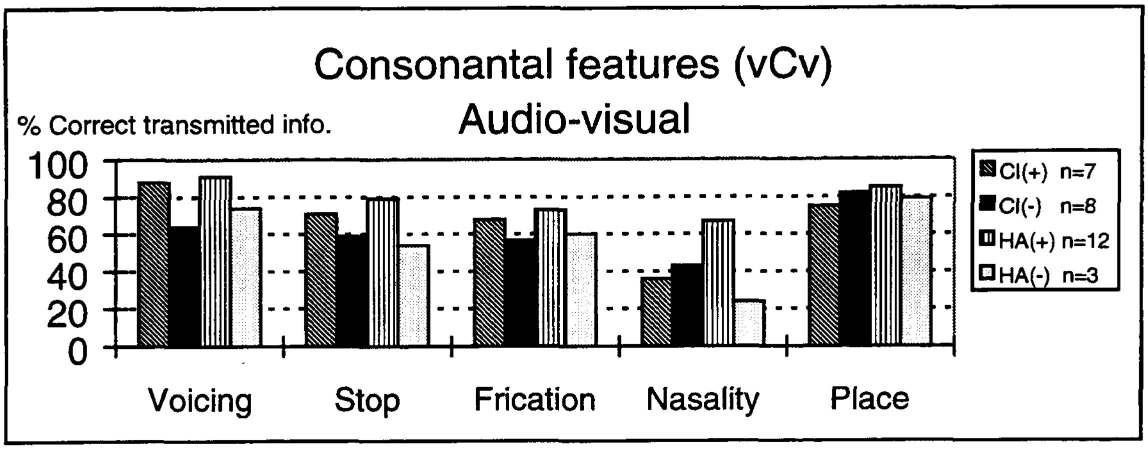
The results on the vCv-test in conditions audiovisual and auditory alone showed that the mean score from the HA(+)-users were very similar to the good performers in the CI-group. The subjects in CI(–) were substantially poorer to identify the consonant features, except for nasals, which were poorly perceived, in average, by both groups of cochlear implantees.

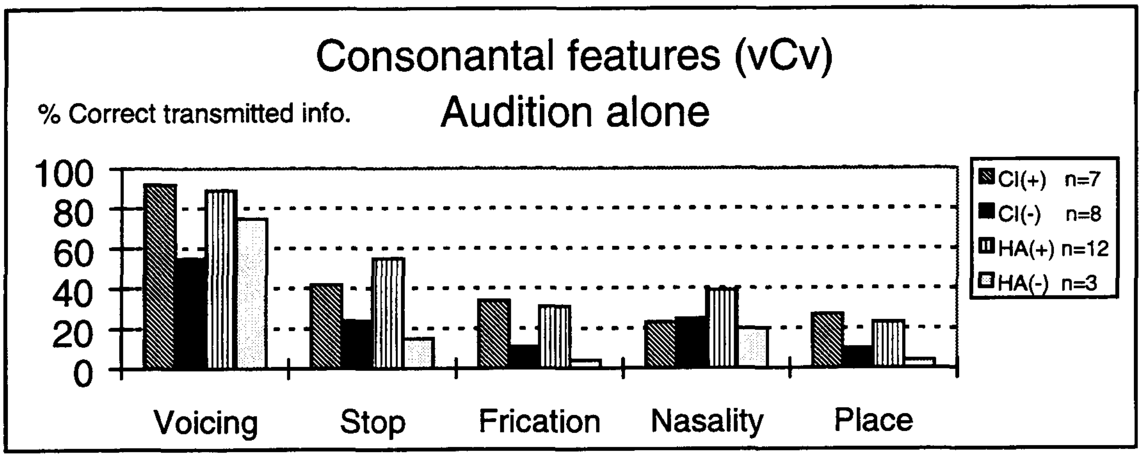
Many cochlear implant research groups have reported results of an analysis of the consonant confusions of patients using different implant devices. Blamey et al. (1987), Dorman et al. (1990), Tye-Murray and Tyler (1989) reported the same results and conclusions regarding consonant recognition: (1) Information transfer scores were relatively high for envelopes features and relatively poor for the place feature; (2) the best patients evidenced relatively high information transfer scores for frication; (3) extracting information from the middle- to high-frequency portion of the auditory spectrum is correlated significantly with high scores on tests of word recognition.

Conclusion

The aim of this study was to obtain some information about differences in speech perception performance for adults with acquired deafness using cochlear implants and adults with a severe-to-profound hearing loss using hearing aids.

It is clear from the results that many of the HA-users as well as the CI-users obtained very good benefit from their devices. In this study, 47% of the cochlear implantees and 80% of the hearing-aid users were able to perceive open speech auditory alone on CDT (>20 words per minute). Both groups of subjects obtained an improvement of 30-35% on average with their aids in the combined condition compared to the lipreading-alone condition. There were large variations within the groups. However, there are





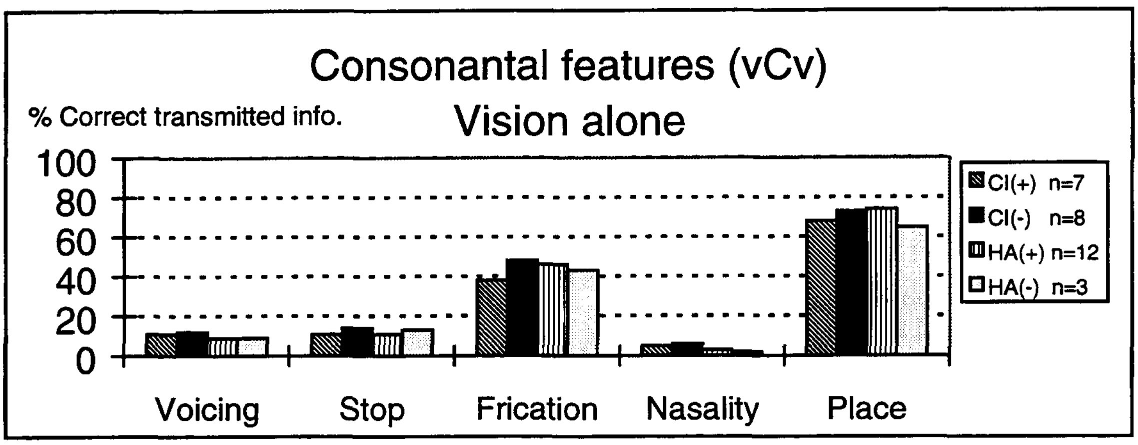


Fig. 9, 10 and 11. Mean percentages of information transmitted for each consonant feature for the two groups of CI(+/–) and HA(+/–) users presented in conditions: audiovisual, auditory alone with assistive device, and vision alone.

some subjects in both groups who derived poor benefit from their aids on the speech perception tests used. The results obtained from the segmental test showed that the better subjects in both groups scored almost 100% transmitted information about the feature voicing. These subjects are also better in perceiving information in the high-frequency domain. Results obtained on suprasegmental test showed that hearing-aid users are better in perceiving prosodic information than the implant users in condition auditory alone.

The support that the severely hearing-impaired users get of a hearing aid during speechreading cannot be predicted from the pure-tone audiogram with any certainty. The conclusion is that no fixed value of mean hearing loss can be used as criteria for implantation.

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