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Improved Speech Perception in Adult Congenitally Deafened Cochlear Implant Recipients

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Objective: To determine whether congenitally deafened adults achieve improved speech perception when auditory and visual speech information is available after cochlear implantation.
Study Design: Repeated-measures single subject analysis of speech perception in visual-alone, auditory-alone, and audiovisual conditions.
Setting: Neurotologic private practice and research institute.
Subjects: Eight subjects with profound congenital bilateral hearing loss who underwent cochlear implantation as adults (aged 18–55 years) between 1995 and 2002 and had at least 1 year of experience with the implant.
Main Outcome Measures: Auditory, visual, and audiovisual speech perception.
Results: The median for speech perception scores were as follows: visual-alone, 25.9% (range, 12.7–58.1%); auditory-alone, 5.2% (range, 0–49.4%); and audiovisual, 50.7% (range, 16.5–90.8%). Seven of eight subjects did as well or better in the audiovisual condition than in either auditory-alone or visual-alone conditions alone. Three subjects had audiovisual scores greater than what would be expected from a simple additive effect of the information from the auditory-alone and visual-alone conditions alone, suggesting a superadditive effect of the combination of auditory-alone and visual-alone information. Three subjects had a simple additive effect of speech perception in the audiovisual condition.
Conclusion: Some congenitally deafened subjects who undergo implantation as adults have significant gains in speech perception when auditory information from a cochlear implant and visual information by lipreading is available. This study shows that some congenitally deafened adults are able to integrate auditory information provided by the cochlear implant (despite the lack of auditory speech experience before implantation) with visual speech information. **Key Words:** Adults—Cochlear implants—Deafness—Lipreading—Speech perception.
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Increasing numbers of congenitally and early deafened adults are presenting for evaluation for cochlear implantation. Why? Satisfied implant users are recommending implantation to their deaf friends. The Deaf community is becoming more open to cochlear implantation. Publicity has increased. Availability has increased.

Cochlear implantation is an effective treatment of deafness, but the degree of benefit is highly variable among individuals. Greater residual hearing, shorter duration of deafness, and younger age at the time of implantation are among the best predictors of superior postimplantation speech perception. Reports of early generation cochlear implants showed that most prelingually deafened subjects who underwent implantation as teenagers or adults rarely obtain significant improvement in open-set speech recognition (1–3). Commonly, the degree of benefit from a cochlear implant is defined simply by auditory sentence recognition testing. Therefore, one could conclude that prelingually deafened adults do not obtain significant benefit from the cochlear implant (4,5). On the basis of this reasoning, these patients are discouraged from undergoing implantation in many implant centers. In addition, because many studies report lack of significant improvement in speech recognition, payment for this expensive intervention is at risk of being denied to this group of patients in the current health care climate in the United States.

With new-generation cochlear implants and advancements in speech processing technology, the best cochlear

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implant users are reaching high levels of open-set speech recognition. Prelingually deafened adult implant candidates might also benefit from these developments. Manrique et al. (6) demonstrated the capability of prelingually deafened adult implant recipients to recognize speech signals using the Nucleus 22 (Cochlear Corporation, Sydney, Australia). Waltzman and Cohen reported improved open-set speech perception in four prelingually deafened subjects who underwent implantation between ages 11 and 20 years using the Continuous Interleaved Sampler speech processing strategy (4). This was an encouraging improvement in comparison with their study of patients with the multichannel Nucleus device using early speech processing strategies wherein there was no statistically significant difference between preoperative and postoperative speech recognition tests (3). In a later study, Waltzman et al. (7) evaluated open-set speech perception in 14 adult prelingually deafened subjects with up to 3 years of postoperative experience with the Nucleus CI24M (Cochlear Corporation, Sydney, Australia) and Clarion cochlear implants (Advanced Bionics Corporation, Sylmar, CA, U.S.A.) using Advanced Combination Encoding, Spectral Peak, and Continuous Interleaved Sampler speech processing strategies. A majority of subjects showed improvement in each of the open-set tests used. Fifty percent of subjects showed improvement in open-set City University of New York sentence recognition, with scores increasing between 2% and 98%. In Schramm et al.'s (8) case study of 15 prelingually deafened adult patients with 12 months' follow-up after cochlear implantation, open-set Central Institute for the Deaf (CID) Everyday Sentences sentence recognition improved in 9 of 15 subjects. Postimplantation scores on CID testing for all patients ranged from 0% to 98%, with nine patients showing improvement compared with preoperative scores (with a range of 0–75%) and six patients scoring more than 40%. Of the six patients who had no correct responses preoperatively on the CID test, three scored significantly better postoperatively, with scores between 13% and 58%.

Although these studies are encouraging, auditory-only speech perception testing might not adequately reflect the benefit a prelingually deafened adult could obtain from an implant. It is well known that sighted listeners use visual information to supplement and enhance hearing, especially in challenging situations. Visual speech perception is an important component of the speech and language skills of hearing-impaired individuals as well. In the case of a profoundly hearing impaired individual, visual cues are the most important source of language information. Deaf individuals can be highly accurate visual speech perceivers (9).

Studies have shown that children with cochlear implants do benefit in the audiovisual (AV) condition compared with the auditory-alone (A) and visual-alone (V) conditions (10). The question for this study was whether individuals with extremely limited auditory experience are able to integrate auditory information from the cochlear implant with the visual speech information. In this study, we evaluated the ability of eight congenitally deafened adult cochlear implant recipients to integrate auditory and visual information. The hypothesis that was tested was that congenitally deafened cochlear implant users can identify more words when presented in AV speech than in A or V speech alone.

PATIENTS AND METHODS

Subjects

The subjects were chosen from a review of all cochlear implant patients at the House Ear Clinic. Fifty-four patients with congenital or early-onset deafness were identified. Twenty-six patients met initial enrollment criteria. All patients who met the enrollment criteria for the study were invited by letter to participate. The enrollment criteria included 1) congenital profound sensorineural hearing loss (hearing loss identified before the age of 2 and thought to be congenital); 2) cochlear implantation as adults (age 18–55 years) between 1995 and 2002 at the House Ear Clinic; 3) current user with at least 1 year of experience using the implant; and 4) use of English, Signed English, and/or American Sign Language as their native language(s). Eight subjects agreed to participate. Eighteen subjects were not enrolled either because they did not respond to the invitation or a secondary review found them to fail the enrollment criteria. Of the eight subjects studied, the cause of hearing loss was hereditary in three cases, maternal rubella in two cases, and unknown in three cases. Seven subjects had a lifetime experience with hearing aids and the remaining subject had only 1 year of experience with a hearing aid. All of the subjects were highly motivated research subjects with college educations. All of the patients were full-time users of their devices. Table 1 lists further demographic information.

Methods

The subjects answered a questionnaire regarding hearing history and communication practices. Clinical histories were obtained by review of records and by personal interviews. Before testing, aided thresholds to warble tone stimuli were obtained. Each subject's processor was assessed for appropriateness of map and sensitivity. The maps were not manipulated before testing. Each subject started their test session with a fully charged processor. Nucleus 24 users were provided with new AA batteries and Clarion users were provided with a fully charged battery pack.

A visual acuity of 20/30 or better on a standard Snellen chart was required for inclusion. Each subject completed a computerized lipreading screening test. The lipreading screening test is composed of 30 videorecorded sentences (11,12) from the list of CID Everyday Sentences (13). Half of the sentences were spoken by a male talker. Participants were tested individually in a quiet room. The prerecorded sentence stimuli stored on DVD were displayed on a 14-inch color monitor approximately 0.5 m from the participant. A videodisk player was controlled by a personal computer. The personal computer was used to present stimuli and to record responses. Playback response collection was controlled by custom computer software. Participants viewed each sentence and then typed at a computer terminal what they thought the talker had said. Passing scores were based on normative data collected for the relevant participant group.

Speech perception testing was performed in A, V, and AV conditions. Testing was performed in a sound-treated booth.

TABLE 1. *Demographic data*

Subject	Age at implantation (yr)	Communication methods	Cause of deafness	Preoperative unaided PTA (dB), Ipsi/Contra	Preoperative aided PTA (dB), Ipsi/Contra	Preoperative HINT (%)	Hearing aid experience	Type of implant	Type of speech processing	Years of implant experience
1	18	Oral, SE	Hereditary	90/89	35/35	4%/22% Ipsi/Contra	Lifetime, AU	N24	ACE 1200	3.1
2	32	Oral, SE	Unknown	105/105	75/65	0 AU	Lifetime, AU	Clarion	MPS	2.9
3	51	Oral, SE, ASL	Hereditary	119/120	98/101	0 AU	Lifetime, AU	Clarion	MPS	2.3
4	55	Oral, SE, ASL	Hereditary	119/115	96/100	0 AU	Lifetime, Ipsi	Clarion	MPS	1.9
5	26	Oral only	Unknown	115/115	85/84	5 AU	Lifetime, AU	Clarion	MPS	3.3
6	34	Oral, SE, ASL	Prenatal rubella	100/101	68/74	0 AU	Infrequent	N24	CIS 900	1.6
7	32	Oral, SE	Prenatal rubella	111/111	86 (Sound Field)	18 AU-(CID)	Lifetime, AU	N24	ACE	4.8
8	34	Oral, ASL	Hereditary	120/116	95/94	0 AU	Lifetime, Ipsi	Clarion	MPS	2.0

ACE, advanced combination encoders; ASL, americal sign language; AU, binaural; CIS, continuous interleaved sampling; Contra, nonimplanted ear; HINT, hearing in noise test; Ipsi, implanted ear; N24, Nucleus 24 (Cochlear Corporation, Australia); PTA, Four-frequency (500, 1,000, 2,000, and 3,000 Hz) average bone conduction threshold; SE, signed english; SPEAK, spectral peak strategy.

Speech was presented at 65 dB sound pressure level in the sound field. The materials were presented via a BETACAM-SP recording of a female speaker with the face filling the display of a 14-inch Sony Trinitron monitor. One hundred fifty IEEE sentences (14) were chosen and categorized into three equivalently difficult sets based on previous testing in the visual-only condition on normal hearing subjects. The average number of words per sentence was eight. Analysis of variance showed that the three sets of 50 sentences (for the A, V, and AV subtests) were not different based on the percentage correct scores of normal hearing subjects. For this study, the order of testing for the A, V, and AV subtests was determined randomly. Each subject was given up to 10 practice sentences immediately before the administration of each subtest.

After being presented with the stimulus sentence, the subject typed on a computer keyboard the whole sentence or any words or parts of words they understood. They were instructed to guess if needed. They had as much time as needed to type their answers and could make changes before submitting the response for each sentence. For all sentence testing, unambiguous typographic errors were corrected before scoring. A custom software program scored the number of correct words per sentence. The software uses a recursive algorithm to find the best word level match between a stimulus and response sentence.

RESULTS

Lipreading Screening

The lipreading screening scores are listed in Table 2. For deaf subjects, 86 is the lowest passing score. It represents one-half standard deviation below the mean of a normative group of deaf lipreaders. With one exception, subject 4, the subjects were expert lipreaders. In general, subjects who had high scores on the lipreading screening test had high scores on the visual sentence subtest.

Speech Perception

The percentages of words correct for the eight subjects are presented in Table 2 and Figure 1 (arranged from lowest to highest AV score). The median for the

TABLE 2. *Speech perception, lipreading screening, and audiovisual tests*

	Subject	HINT (%)	Lipreading screening	V (% words)	A (% words)	AV (% words)	Relative gain (R_v) (%)
	1	46	126	25.8	26.2	53.3	37
	2	0	168	28.4	6.2	56.8	40
	3	0	145	29.2	0.5	31.9	4
	4	0	72	18.4	0.8	16.5	−2
	5	83	208	58.1	49.4	90.8	78
	6	0	104	12.7	0	18.6	7
	7	26	141	26.0	11.0	48.2	30
	8	25	154	18.7	4.2	53.6	43
Mean				27.1	12.3	46.2	29.5
SD				13.7	17.3	24.1	26.5
Median				25.9	5.21	50.7	33.5

A lipreading score of 86 is considered a passing score for deaf subjects.
A, auditory-alone; AV, audiovisual; HINT, hearing in noise test; V, visual-alone.

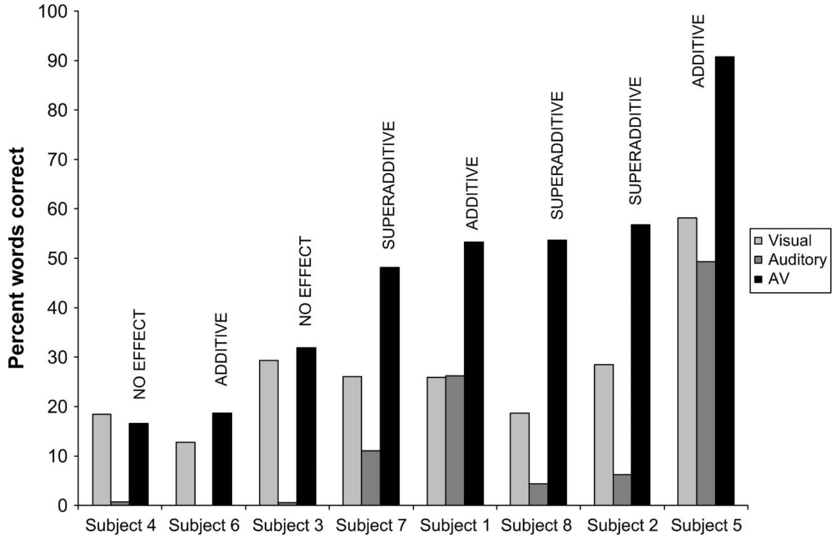

FIG. 1. A, V, and AV sentence testing with percentage of words correct. The AV condition is labeled with regard to the effect of combined condition: No effect, AV = V; additive, A + V = AV; superadditive, AV > A + V.

sentence testing were as follows: V, 25.9% (range, 12.7–58.1%); A, 5.2% (range, 0–49.4%); and AV 50.7% (range, 16.5–90.8%). Four subjects had better than 50% words correct in the AV condition. The three subjects who scored less than 1% words correct in A had the lowest words correct in the AV condition. The three subjects who scored between 4% and 11% in A (subjects 2, 7, and 8) scored 48% or more in AV. As a group, the eight subjects performed significantly better in the AV condition than in either A ($p = 0.008$) or V ($p = 0.016$) conditions (Wilcoxon signed ranks test).

Three subjects (subjects 1, 5, and 6) had a simple additive effect of speech perception in the AV condition where the percentage of words correct in the AV condition approximated the percentage of words correct obtained by adding the A and V scores (AV = A + V). Three subjects (subjects 2, 7, and 8) had AV scores substantially greater (by more than 10%) than what would be expected from a simple additive effect, suggesting a superadditive effect (AV > A + V) of testing in the AV condition compared with testing A and V separately. Two subjects (subjects 3 and 4) had scores in the AV condition very close to the V condition, suggesting no effect of the addition of auditory information.

Subjectively, six of eight subjects reported better speech perception with the cochlear implant. Subjects 2 and 8 did not feel their speech perception was improved with the implant, despite understanding more than 50% of words in the AV condition.

Relative Benefit

A method of calculating relative benefit from the addition of a second mode of information was described by Lachs et al. (15). This method is helpful for assessing the gain in accuracy in the AV condition relative to the accuracy in a unimodal condition normalized to the amount of improvement that is possible based on the unimodal score. The relative gain in speech perception attributable to the addition of auditory information over the V condition can by calculated by the following formula: $R_v = (AV - V)/(100 - V)$, where AV is the speech perception score in the audiovisual condition and V is the score in the visual-only condition.

For the subjects in this study, the median R_v is 34%, with a range of −2 to 78%. Individual scores are listed in Table 2. All but one subject had a positive gain. Five subjects had relative gains in the AV condition over the V condition greater than 30%. Two subjects showed only a small positive gain.

DISCUSSION

Despite highlighting definite improvement in speech recognition in a proportion of prelingually deafened adult cochlear implant patients, some previous studies conclude that in most patients the effect is limited and in some patients there is no benefit (2–5). However, auditory-alone word and sentence recognition scores are not exclusively representative of how much a patient benefits from a cochlear implant.

Several authors have highlighted significant improvements in auditory skills, including detection and identification of environmental sounds, improvement of lipreading, improvement in speech production, and improvement in self-reported quality of life in prelingually deafened adult cochlear implant recipients (1–4,16). Sustained use of the implant may also be a good indicator of subjective benefit. Even with the earliest devices, some patients benefited. Eisenberg (16) reported that 8 of 12 prelingually deafened adult implant patients in her study used their implants daily and were able to enjoy music and hear horns and the calling of their names. Some of her patients also reported that they were more independent an social and less lonely (16). In Waltzman et al.'s article, all 14 subjects continued to use the device on a regular basis and reported that their communication skills were enhanced by the implant, including the subjects who did not show improvement on speech recognition scores (7). On the basis of results from the Performance Inventory for Profound and Severe Loss questionnaire, 7 of 15 subjects in a study by Schramm et al. (8) (who obtained scores ranging from 0–41% on CID sentences) reported improvement in understanding of environmental cues and understanding speech with no visual cues. In Zwolan et al.'s (1) study, 11 of 12 subjects expressed some degree of satisfaction and 9 indicated by questionnaire that the device improved their lipreading ability.

One reason for apparent discrepancies between speech recognition testing and patient-reported outcomes may be the limitations of auditory-only speech perception testing. Normal hearing and hearing-impaired adults integrate auditory and visual cues to enhance speech perception, especially under difficult listening conditions (17–20). Prelingually deafened children with cochlear implants are able to integrate visual cues with auditory information provided by the cochlear implant (10,15).

The gain in speech understanding in the audiovisual mode for adult postlingually deafened cochlear implant patients has been documented in a only few studies (21). Detailed work on the mechanisms of AV integration is an evolving field of research. To what degree and by what mechanisms do adult implant patients integrate the highly degraded speech signal presented via the cochlear implant? Goh and colleagues (20) reported an analysis of one adult cochlear implant patient's AV speech recognition. The patient was deafened at the age of 29 and he underwent implantation with a Clarion device at age 31. At the time of the study, he had 4 years' experience with the device and was an excellent performer based on City University of New York scores of 92% in the A condition. He was tested for understanding of 18 sentences that were digitized and degraded to represent sine-wave speech. His scores in A, V, and AV conditions were compared with those of a group of normal-hearing subjects. In the AV condition, his score was 90%, which represented a gain of 78% by the addition of visual cues over the A condition (in which he scored 53%). Although in the A condition his scores were lower than normal-hearing subjects, his performance in the AV condition was comparable to the average performance of normal-hearing controls. They concluded that the auditory information provided by the implant was useful in multimodal speech, despite the absence of the speech cues traditionally thought of as critical elements of speech understanding.

Giraud and Truy (22) performed positron emission tomography in postlingually deafened adult cochlear implant users while they listened to speech with their eyes closed. They observed activation of the visual cortex in both normal hearing and cochlear implant subjects. There was additional activation of the fusiform/perirhinal region (a region that is thought to invoke visual images) and the midfusiform area (known as the face region) in cochlear implant subjects but not in controls. The authors concluded that higher visual cortical areas participate in processing of speech in cochlear implant subjects. Whether and to what degree patients with congenital or early acquired deafness retain the ability to use multimodal speech is unknown.

The subjects of this study would be considered poor candidates by many centers. They were congenitally deafened, had long-term deafness (between 18 and 45 years), and had minimal residual hearing. However, in general, they were good lipreaders and had worn hearing aids for the majority of their lives. At the House Ear Clinic, these characteristics are thought to correlate with subjective satisfaction in prelingually deafened patients after implantation and are incorporated in the guidelines for preoperative selection and counseling.

Despite poor performance on standard speech perception tests (Hearing In Noise Test, 0–83%; median, 12.5%), the subjects in this study were all satisfied, full-time cochlear implant users. For all eight subjects as a group, the AV scores were significantly better than A or V scores. Three subjects appeared to have a simple additive effect in the AV condition. The remaining three subjects performed better in the AV condition than what would be estimated by simple addition of scores obtained in the A and V conditions (a superadditive effect).

Two subjects did not show improvement in speech understanding in the AV condition compared with the unimodal conditions. One of these two subjects performed a few percentage points worse in the AV condition than in the V condition. His understanding of auditory signal was very poor, having scored less than 1% in the A condition. The degradation in AV speech understanding of only a few percentage points is probably insignificant. Despite this lack of benefit in objective testing, these two patients continued to be full-time users and reported satisfaction with their devices. This suggests that our understanding of benefit remains incomplete in this group of patients. Ongoing research will attempt to quantify subjective benefit.

Overall, the results suggest a significant capacity for multimodal speech perception in congenitally deafened adult cochlear implant patients. AV speech perception is a complex system of central processing that incorporates transcription of auditory and visual features, integration of auditory and visual features, individual linguistic knowledge, individual memory and attention abilities, and understanding of context (23–25). For cochlear implant patients, especially those with little auditory experience, the implications of presenting a novel signal to the central auditory system cannot be underestimated. To what degree the novel signal can be integrated and whether it could cause cortical reorganization, interference of visual and auditory speech processing mechanisms, or overloading of the cognitive language capability is unknown. A better understanding of the mechanisms of AV speech in cochlear implant patients may guide advancements in technology and direct postoperative rehabilitation.

CONCLUSION

Some congenitally deafened subjects who undergo implantation as adults have substantial speech perception benefit from the auditory signal. Despite scoring poorly in the auditory alone condition, there were significant gains in speech perception when both auditory information from a cochlear implant and visual information by lipreading were available. This study shows that some congenitally deafened adults are able to integrate auditory information provided by the cochlear implant (despite the lack of auditory speech experience before implantation) with visual speech information.

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