Effects of Delayed Second Cochlear Implant

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Abstract Objective Since Helms’ successful bilateral cochlear implantation with good results in 1996, there have been increasing number of reports on bilateral cochlear implantation. Most second device have been implanted within one year after the first. Considering effects of long time auditory deprivation, it is not clear whether a delayed second cochlear implant serves to add additional benefits and how it may interact with central nervous system plasticity. Methods Three cases who received delayed second cochlear implants at People's Hospital of Peking University from 2002 to 2005 were reviewed. The interval between the first and second implants was longer than 2 years in all three patients. Sound perception, and unilateral/bilateral speech discrimination in quiet and noise were evaluated. In addition, GAP detection test was conducted in one patient. Results In one case, having both implants on provided improved performance compared to using only one implant both in quiet and noise. Presumably due to visual interference from lip-reading or short interval between second implant and testing, one patient showed no improvement from using the second implant either in quiet or noise, while the last case demonstrated additional benefits from the second implant only in quiet. In all three patients, performance in recognizing the four tones in Mandarin was superior over word recognition. Conclusions Considerable plasticity in the cerebral auditory center is preserved, despite long acoustic deprivation in some children who have received unilateral cochlear implant. Delayed second implants can result in significant improvements in some of these children. Visual interference from lip-reading may be an obstacle during retraining. The better recognition of tones in the Mandarin language may represent a different sound discrimination mechanism in the auditory system, although it may also be related to the signal processing mechanisms of the implant used (MED-EL COMBI 40+).

Keywords bilateral cochlear implant; auditory deprivation

Introduction

Cochlear implantation has been established as an effective and safe method of rehabilitation for those with profound deafness. But for economic reasons, unilateral implantation is considered to be the mainstream today. Numerous studies indicate that after unilateral cochlear implantation many patients show high levels of speech understanding, allowing them to conduct everyday communication, such as face-to-face conversation and using telephone. This auditory prosthesis has greatly improved life qualities of the cochlear implant users, and facilitated children's mental development, making normal education available to pediatric recipients. However, results also showed that speech discrimination scores were just passable in competing noise. It is well known that noise reduction and acoustical orientation abilities of the human auditory system depend on the time, level, and spectral differences between sound signals sensed by the two ears; and that subjects with normal binaural hearing have better speech perception scores in background noise or in reverberant environment. Bilateral cochlear implantation may be an effective solution to rebuild binaural hearing. In 1996, Helms et al. first performed a bilateral cochlear implantation to restore patient's binaural hearing and reported benefits.
from bilateral stimulation\textsuperscript{[12]}. Since then, the number of bilateral implantation has increased gradually. Several reports have demonstrated that, compared with unilateral implantation, bilateral implantation helps rebuild binaural hearing, significantly promotes user’s speech understanding, especially in background noise, and restores spatial orientation abilities \textsuperscript{[13-16]}. However, most bilateral implantations have been performed within one year of the first implant. Considering effects of long time auditory deprivation, it is not clear whether a significantly delayed second cochlear implant will provide additional benefits and whether there is sufficient plasticity in the auditory center after a long delay following the first implant. From 2002 to 2005, four patients received second cochlear implantations at the People’s Hospital of Peking University, with delays longer than two years. Contact with one of the four patients was lost during follow-up. The rest three cases are reviewed in this paper, regarding their sound and speech recognition tests results. The impact of bilateral cochlear implantation on speech discrimination and the role of central plasticity in delayed bilateral implantation are discussed.

Material and methods

Subjects

Three children (2 boys and 1 girl) with profound congenital hearing impairment who were implanted with MED-EL COMBI 40 + bilaterally were included in this study. The mean preoperative auditory thresholds were greater than 100 dB HL. The patients’ age ranged between 11 and 12 years. The interval between the first and second implants was between 2 and 5 years. The 2 boys received their first implants in the right ear at ages 6 and 7, while the girl had her first implant in the left ear at 8.

All recipients lived in Beijing and were the single child in their families. Parents of these children were well educated, with stable and above average incomes. There was no family issue-related stress. All subjects attended regular schools, with good grades, and showed willingness to communicate with classmates. Surveys among their classmates suggested no significant difficulties in communication with the patients related to their hearing conditions. Subjects 2 and 3 acquired lip-reading and speech skills through more than two years of regular lip-reading and speech training before their first implantation.

Tests

Test 1

Monosyllable recognition was tested in quiet and noise under three conditions: with both implants on; left implant on only; and right implant on only. Monosyllable words were presented at 55 dB SPL. When noise was added, the signal/noise (S/N) ratio was kept at 5 dB. Azimuths of test material and noise were 0 degree from a distance of 1.5 meters. Tests were conducted in an anechoic chamber. No changes were made to implant speech processor parameters. Instructions and practices were given before testing until subjects completely understood and were familiar with the tests. Obtained from Beijing Tongren Hospital, speech materials used in the tests were composed of single-syllable words recorded in male voice with 3 second intervals between words to give the subject adequate response time. Word recognition scores were based upon correct repeats by the subject. The subject’s ability to correctly recognize the tone of the word was simultaneously assessed. No real-time feedback regarding response correctness was provided.

<table>
<thead>
<tr>
<th></th>
<th>Recognition score in monosyllable</th>
<th>Recognition score in Chinese four-tone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quiet</td>
<td>Noisy (s/n: 5dB)</td>
</tr>
<tr>
<td>Subject 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Subject 1</td>
<td>74%</td>
<td>58%</td>
</tr>
<tr>
<td>Subject 2</td>
<td>24%</td>
<td>8%</td>
</tr>
<tr>
<td>Subject 3</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>Subject 1</td>
<td>96%</td>
<td>88%</td>
</tr>
<tr>
<td>Subject 2</td>
<td>74%</td>
<td>60%</td>
</tr>
<tr>
<td>Subject 3</td>
<td>78%</td>
<td>76%</td>
</tr>
</tbody>
</table>

1: the first implant on  2: the second implant on  3: both on

Subject 1 demonstrated improved performance with bilateral stimulation over unilateral stimulation whether in quiet or in noise. There was no significant difference between the two conditions in Subject 2. In Subject 3, bilateral stimulation was superior over unilateral stimulation in quiet, but the difference was not significant in noise. All patients showed better tone recognition capability than word recognition with no significant difference between in quiet and in noise.
to the subjects during the tests.

All these tests were implemented in November 2005, three years and two months after Subject 1's second implantation and four months after the second implantation for Subjects 2 and 3.

**Test 2**

The subject was asked to read a short essay in a natural manner. Four normal-hearing Mandarin speaking adults scored the understandability of the reading on a scale from 0 to 4, with 0 representing normal reading and 4 indicating severely impaired understandability. The three patients were tested separately.

**Test 3**

This test was conducted in Subject 1 at the time of first fitting of the second device, and at one month and five months later, and measured the subject's ability to detect a GAP between continuous noise and to correctly recognize monosyllable words.

Testing was conducted in an EMI. A loudspeaker was set 1.5 meters from the midpoint of subject's head at the level of the tested ear. Gaussian white noise was presented for a duration of 2.5 seconds at 60dB SPL. A GAP was inserted into the noise. The duration of GAP was gradually reduced from 21 to 0 ms. Step length was 16ms, minimum at 1 ms. The GAP threshold (the shortest GAP that the subject could reliably detect) was approached in a one-up/three-down mode. The subject was allowed to practice before the test. Evaluations were performed to the left implant in Subject 2 one month after binaural stimuli and right implant in subject 3 five months after binaural stimuli respectively.

Monosyllable words recognition test was conducted in the same fashion as in Test 1.

**Results**

**Test 1**

Table 1 shows results of monosyllable word recognitions and Mandarin tone tests from the three subjects.

Subject 1 demonstrated improved performance with bilateral stimulation over unilateral stimulation whether in quiet or in noise. There was no significant difference between the two conditions in Subject 2. In Subject 3, bilateral stimulation was superior over unilateral stimulation in quiet, but the difference was not significant in noise. All patients showed better tone recognition capability than word recognition with no significant difference between in quiet and in noise.

**Test 2**

All subjects received a score of 1, representing minimally impaired articulation capability that did not cause significant deterioration in understandability.

**Test 3**

The results of GAP threshold test and speech test for Subject 1 are shown in Table 2.

**Discussion**

The three patients in this study received the same model of devices in both sides. They received their first implantation at similar ages. Post-operative speech abilities, family environments and school performance were similar. However, their experiences during the early language development and the delay between the first and second implantations were different. An investigation of their post-implantation auditory/speech functions may therefore help define the effects of bilateral implantation and elucidate plasticity of central auditory system.

Monosyllable words were used in this study to focus on testing sound signal processing and to minimize interference from associative and meaning effects\(^{18}\). In normal hearing, advantages of binaural hearing have been attributed to three effects: the head shadow effect, the squelch effect and the summation...
effect. Users of bilateral cochlear implants may also benefit from these effects in rebuilding binaural hearing. Consequently, bilateral implantation can provide significant advantages over unilateral implantation, including improved speech recognition in various listening situations and sound localization\textsuperscript{13-16}.

Subject 1 showed zero word recognition and was unable to detect GAP when the second device was first switched on and used unilaterally. This may be due to lack of adequate sound signal processing in the auditory system on the side of the second device as a result of long auditory deprivation. It takes time for auditory cortices to regain speech recognition function \textsuperscript{17}. The good word recognition scores on the opposite side indicates that the auditory and speech systems on the two sides may develop relatively independent of each other. Binaural hearing depends not only on input from both ears, but more importantly on the integration process at the cortical level, which develops after birth, possesses high degree of plasticity and can be lost under certain circumstances.

Subject 1 consistently demonstrated improvement in GAP detection and word recognition performance along with time either using the first implant, the second implant or both. This is an indication that even in the presence of intact auditory-speech pathways with well preserved functions, gaining binaural hearing in bilateral CI users will still require a process of learning and training. While bilateral cochlear implantation provides an opportunity for improved speech recognition, training following implantation is of crucial importance.

There was no significant difference in articulation capabilities among the three subjects. However, Subject 1’s word recognition scores were noticeably better under all test conditions than the other two subjects. We speculate that the difference may be related to the longer delay for the second implant, which may lead to increased auditory deprivation, and the shorter interval between second implantation and testing in the latter two patients. In addition, both Subjects 2 and 3 had received systematic lip-reading training for longer than 2 years, which may result in suppression of auditory recognition by dependence on visual cues.

These results suggest that a person’s learning experience at a young age plays an important role in his auditory/speech function development. Speech development depends on integration of information from auditory, visual and somesthetic systems. While auditory cues play a dominant role in language development, inputs from other systems are also capable of facilitating speech functions and can be competitively repellent to the auditory system. The development of speech areas in the brain depends on natural language acquisition at young ages \textsuperscript{9}. It is possible that speech development in Subjects 2 and 3 may have been substantially influenced by visual input, which results in invasive deprivation to auditory cortices, leading to poor monosyllable word recognition scores even after long time use of bilateral CIs.

GAP threshold, the shortest GAP that can be reliably detected by a subject, represents the sensitivity of the auditory system in sensing a sudden sound alteration in time. For adults with normal hearing or mild hearing loss, GAP threshold correlates with speech recognition \textsuperscript{10, 11}. This is reflected in results of test 3 in Subject 1. The subject's GAP threshold reached 7 ms(within normal limits) at one month following second device switch-on, indicating regain of time discrimination on the side of the second implant, and continued to improve afterward along with benefits from binaural effects.

While landmarks of their brain development were apparently comparable, the three children demonstrated significantly different hearing deprivation effects. Longer delays between the two implantations and shorter interval between the second device switch-on and testing may count for some of the differences. Two types of auditory deprivation may have been involved in these patients: deprivation from lack of auditory input(as in all three subjects) and from substitution by visual cues (as in Subjects 2 and 3). Different from Subject 1, who developed no substitute language function, Subjects 2 and 3's auditory language development was further suppressed by their dependence on visual cues from lip-reading acquired through training at young ages. This may also have affected the plasticity of their central auditory systems. The data from these three patients seem to suggest that pure acoustic deprivation has limited effects on the development of the auditory/language system and the patient may retain useful plasticity in the central auditory system for hearing rehabilitation. In contrast, auditory deprivation from a combination of lack of sound input and substitute communication skills may have increased impact on plasticity of the central auditory system. Obviously, more data are needed to better understand the degree of the plasticity loss under such circumstances and if it is.
recoverable.

The data also serve to emphasize the importance of differentiating auditory language dysfunction from sound deprivation and from visual input interference when engaging post-implantation patients. Individualized retraining strategies are necessary and interference by lip-reading and sign language should be minimized, while auditory cues should be emphasized.

The Mandarin tones are based upon frequency modulation of the vowel elements, resembling music to a certain extent. The three patients in this study showed minimal difficulties in recognizing the four tones in Mandarin, both in quiet and noise. This may be due to the fact that tone recognition is an essentially central, process, separate from speech recognition, with minimal dependence on cochlear processing or on binaural effects. It is also possible that the signal processing mechanism of the implants used in these patients may affect tone recognition as well.

**Conclusions**

Bilateral cochlear implantation can provide additional benefits in speech recognition in both quiet and noise for patients even when the second implant is delayed for longer than 2 years. However, the benefits can be affected by auditory deprivation and tend to diminish in patients with invasive deprivation such as by visual input suppression. Whether this disadvantage can be overcome needs further investigation.

Patients implanted with MED-EL COMBI 40 + demonstrated excellent Mandarin tone recognition, which may represent an independent mechanism.

**References**