The Journal of International Advanced Otology

J Int Adv Otol 2015; 11(2): 98-103 • DOI: 10.5152/iao.2015.424

Original Article

Factors Contributing to Speech Performance in Elderly Cochlear Implanted Patients: An FDG-PET Study: A Preliminary Study

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OBJECTIVE: The purpose was to evaluate brain plasticity that contributes to speech performance after cochlear implantation (CI) in postlingual elderly (>60 years) patients.

MATERIALS and METHODS: Fifteen elderly postlingual deaf patients who underwent preoperative brain fluorodeoxyglucose positron emission tomography (FDG-PET) and were followed-up for more than 1 year after CI were included. The mean age of these patients was 64.6 years (range, 60–80 years). Based on their sentence score at 1 year after CI surgery, the patients were classified into two groups: *poor performers* (CID score of <80) and *good performers* (CID score of ≥80). The duration of deafness, age at operation, preoperative residual hearing, and preoperative brain metabolism were analyzed. SPM5 software was used for FDG-PET image preprocessing and statistical analysis.

RESULTS: Neither deafness duration nor preoperative residual hearing was associated with speech performance. The age at operation had little association with speech performance. Deaf patients whose brain metabolism was higher in frontotemporal regions became good CI users but those with higher metabolism in visual association areas became poor CI users. No significant cortical area of higher metabolism was associated with the duration of deafness.

CONCLUSION: Overactivation in the visual processing pathway correlated with a poor CI outcome at 1 year. Deaf patients who are going to be poorer performers with CI devices maintain visual information processing during preoperative silent resting periods.

KEYWORDS: Cochlear implantation, deaf, PET imaging

INTRODUCTION

The number of elderly individuals (>60 years old) with late-onset hearing loss and meeting surgical indications for cochlear implantation (CI) is progressively increasing. Considering life expectancy and perioperative risk in old age, it would be very helpful to predict factors for successful results after CI in the elderly. In children, several known factors explain 35–51% of variance in cochlear implant outcomes. Age at implantation, duration of deafness, duration of device use, mode of communication, and strategy of coding are some of these factors [1]. Among these, age at implantation is a major determinant of "pediatric" CI candidacy [2]. The reason why age has an important prognostic value is associated with brain plasticity; that is, age itself independently is not a major determinant, but rather, prelingual auditory deprivation, which causes brain plasticity, is. A low metabolic rate in the temporal cortices before CI is related to a more favorable speech perception outcome after CI [3-6]. There is controversy regarding functional reorganization in postlingual deaf adults [7] because the adult brain has already completed functional organization. However, cross-modal neural reorganization occurs even in the mature human brain [3, 8]. After brain maturation, auditory deprivation leads to functional reorganization of the auditory cortex by transiently decreasing the neuronal activity in the auditory cortices. This decreased neuronal activity and functional reorganization may be a link between hearing loss and dementia as some authors have claimed that hearing loss is independently associated with incident all-cause dementia [9]. Plasticity is prominent in the superior temporal and anterior cingulate gyri of a sensory-deprived mature brain and militates against post-implantation improvement in patients with CI [3]. Many studies have examined brain activity using ^{18}F-fluorodeoxyglucose (FDG) positron emission tomography (PET) imaging to reveal this difference in brain plasticity. They showed that the cortices of individuals with cochlear implants who achieve successful levels of speech perception activate more areas than in those with normal hearing when listening to speech stimuli [10, 11]. PET studies also show that the right secondary auditory and auditory association cortices are significantly activated in response to words, prose [12], and

This study was presented at the 6th Asia Pacific Symposium on Cochlear Implants and Related Sciences (APSCI), 1 November 2007, Sydney, Australia.

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Submitted: 22.07.2014 **Revision received:** 27.05.2015 **Accepted:** 30.05.2015

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sentences [13] in individuals with a cochlear implant who have high levels of speech perception but not in those who have low speech perception abilities [12, 13]. However, these previously published results are based on postoperative differences in brain plasticity. It would be more valuable clinically if plasticity changes in the brain could be elucidated to predict the prognosis of CI before surgery, particularly in elderly postlingual deaf subjects.

The decision to perform a CI operation is more complicated for elderly deaf patients. For example, the natural senile degeneration of the central auditory nervous system may be an unfavorable prognostic factor. Additionally, a young deaf patient is expected to benefit from an implanted CI device for a long period, but this is not the case for elderly patients. This study was designed to evaluate brain plasticity that contributes to speech performance after CI in postlingual elderly (>60 years) patients. Preoperative ^{18}F-FDG-PET imaging of the brain was analyzed and correlated with postoperative speech performance.

MATERIALS and METHODS

Patients

Fifteen elderly postlingual deaf patients (10 males and 5 females) aged 60–80 years (mean±standard deviation: 64.7±5.1 years) who underwent CI in Seoul National University Hospital were recruited. The subjects underwent preoperative PET imaging. The PET scans were analyzed in correlation with sentence perception, which was assessed 1 year post-implantation. The patients were examined for aided pure tone audiometry (PTA) and unaided PTA before CI surgery to check their remaining hearing ability. The subjects agreed to sign a written informed consent, which was approved by the Seoul National University Hospital institutional review board (IRB No. C-0701-063-196).

^{18}F-FDG-PET Imaging

A Siemens-CTI (ECAT EXACT47, Knoxville, USA) PET scanner (sensitivity 214 kcps/μCi/min, axial resolution 4.3 mm, spatial resolution 6.1 mm, BGO crystal detector) was used for preoperative ^{18}F-FDG-PET imaging. Thirty minutes before the PET scan, <370 MBq of intravenous ^{18}F-FDG was injected. While waiting for the scan, the patients were seated in a room with a noise level of <70 dB SPL. The patients were not able to hear anything because their residual hearing was inadequate at this level, even with a hearing aid. The metabolic activity of the brain was interpreted as spontaneous brain metabolism during silence. For more than 20 min, 47 slices of brain emission images were acquired during an emission scan. Using a filtered back-projection method, emission images were reconstructed with a pixel size of 2.1×2.1×3.4 mm in a 128×128×47 matrix with a Shepp filter and a cut-off value of 0.35 cycles/pixel. Attenuation was corrected in all reconstructed images, and to obtain sagittal and coronal images, transaxial images were realigned. Reference T1-weighted high-resolution MRI images and brain surface were used to display the results.

Speech Perception Scores

The Central Institute for the Deaf (CID) scores were used to measure speech perception ability (with auditory cues only). The CID Everyday Sentence test is a standardized open-set test that is suitable for testing adults with severe to profound hearing impairment [14]. Test results were obtained approximately 1 year after implantation. Twenty commonly used sentences were presented to each subject without visual cues, and the subject was instructed to listen to them and then repeat them. Within each sentence, words that had been repeated correctly were scored. The CID score is defined as the ratio of correct responses to total trials. Based on the CID score at 1 year after CI surgery, the patients were classified in two groups: *poor performers* (CID score of <80) and *good performers* (CID score of≥80).

PET Scan Analysis

Matlab 7 (Mathworks Inc., Natick, USA) and SPM5 (University College London, UK) were used for image preprocessing and statistical analysis. Significant increases and decreases in regional cerebral metabolism were estimated by comparing PET images between good and poor performers using t statistics for every voxel.

Data Analysis

We recorded the CID score, hearing status, age, deaf duration, and brain activity before surgery and compared all these factors between good and poor performers. A p-value of <0.05 was considered significant for all comparisons. For strict threshold control of temporal hypometabolism, a statistical threshold of p<0.005 was used in PET data correlation analysis. SPSS v13.0 (SPSS Inc.; Chicago, IL, USA) was used to determine correlation (Spearman) and difference in means (Mann–Whitney *U* test).

RESULTS

Comparison of Clinical Factors

According to the CID score at 1 year after CI surgery, 4 patients were classified as poor performers and 11 patients were classified as good performers. Data related to the comparison between the good and poor performers are summarized in Table 1. The average CID score of the good performers 1 year after CI was 94.7±7.3 and that of the poor performers was 46.5±18.6 (p=0.003). The pre-implant CID score was 2.3±3.8 in the good performers and 0.0±0.0 in the poor performers (p=0.462). The difference between postoperative and preoperative CID scores was almost identical to the postoperative CID score in all patients. The deaf duration was 208.5±266.9 months in the poor performers and 80.2±105.9 months in the good performers. Age at operation of the poor performers was 63.3±2.4 years and that of the good performers was 65.2±5.7 years, which showed no difference. The unaided pure-tone average (PTA) threshold was 107±12.9 dB HL in the poor performers and 97.7±16.7 dB HL in the good performers. The aided PTA threshold in the poor performers was 78.3±13.5 dB HL and 69.5±14.9 dB HL in the good performers. Neither the aid-

Table 1. Analysis of clinical data for poor and good performers

	Poor performers (n=4)	Good performers (n=11)	p
1 year CID (%)	46.5±18.6	94.7±7.3	0.01
Duration of deafness (months)	208.5±266.9	80.2±105.9	0.21
Age at OP (years)	63.3±2.4	65.2±5.7	0.79
Unaided PTA preOP (dB)	107±12.9	97.7±16.7	0.39
Aided PTA preOP (dB, n=9)	78.3±13.5 (n=3)	69.5±14.9 (n=6)	0.44

CID: Central Institute for the Deaf

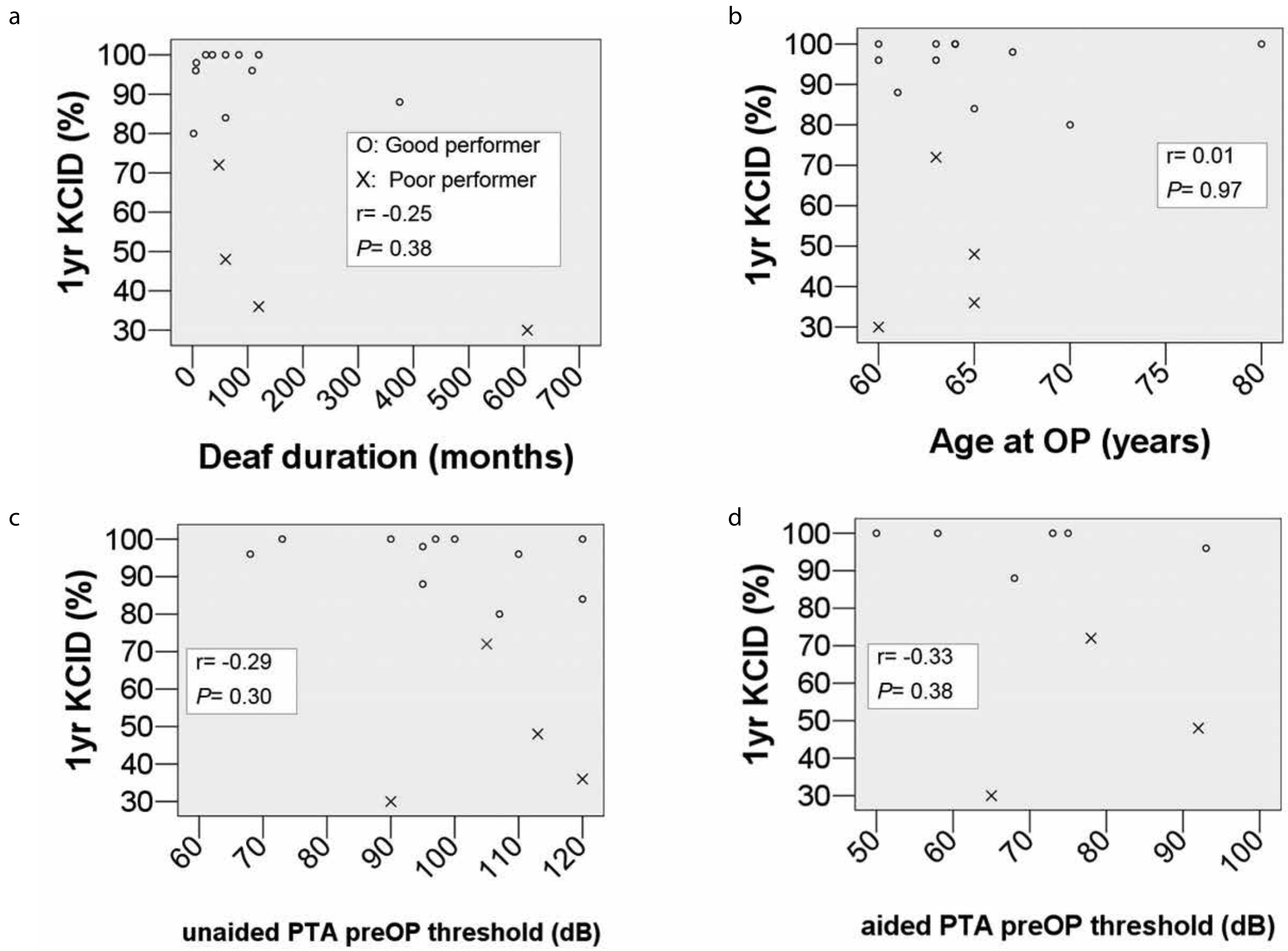

Figure 1. a-d. Correlation analysis between the 1-year Central Institute for the Deaf (CID) Sentence test score after cochlear implantation and other clinical factors. No differences in deaf duration (a), age at operation (b), unaided preoperative pure-tone audiometry (PTA) threshold (c), and aided preoperative PTA threshold (d) were observed

Table 2. Difference in preoperative metabolism in dominant brain regions between good performers and poor performers

	L/R	Brain region	MNI coordinate	Cluster size	BA	Voxel T	P corr (FDR)
Good performers*	L	Inferior temporal gyrus	-66-24-22	84	20	4.24	0.846
	L	Premotor area	-46-8 62	56	6	3.85	0.846
Poor performers**	R	Cuneus	28-80 8	104	18	3.32	0.993

*P uncorr=0.005, k=50
**P uncorr=0.01, k=50
MNI: Montreal Neurological Institute and Hospital coordinate system; BA: Brodmann areas; corr: corrected; FDR: false discovery rate; uncorr: uncorrected

ed nor unaided PTA threshold was different between the good and poor performers. The correlation between the postoperative 1 year CID score and other clinical factors is plotted in Figure 1. No significant correlation was observed between the postoperative 1 year CID score and deaf duration, age at operation, preoperative unaided PTA threshold, or preoperative aided PTA threshold.

Preoperative PET Comparison

Significant differences in glucose metabolism were found between the two groups (Table 2). The brain regions that exhibited different metabolic activities between the two groups are displayed in Figure 2. The good performers showed significantly greater metabolic activity in the inferior temporal gyrus and premotor area, whereas the poor performers showed significantly higher metabolic activity in the cuneus (a smaller lobe in the occipital lobe known for its involvement in basic visual processing). Deaf patients whose brain metabolism was higher in frontotemporal regions became good CI users, but those with higher metabolism in visual association areas became poor users. No significant cortical area of higher metabolism was associated with the duration of deafness (results not shown).

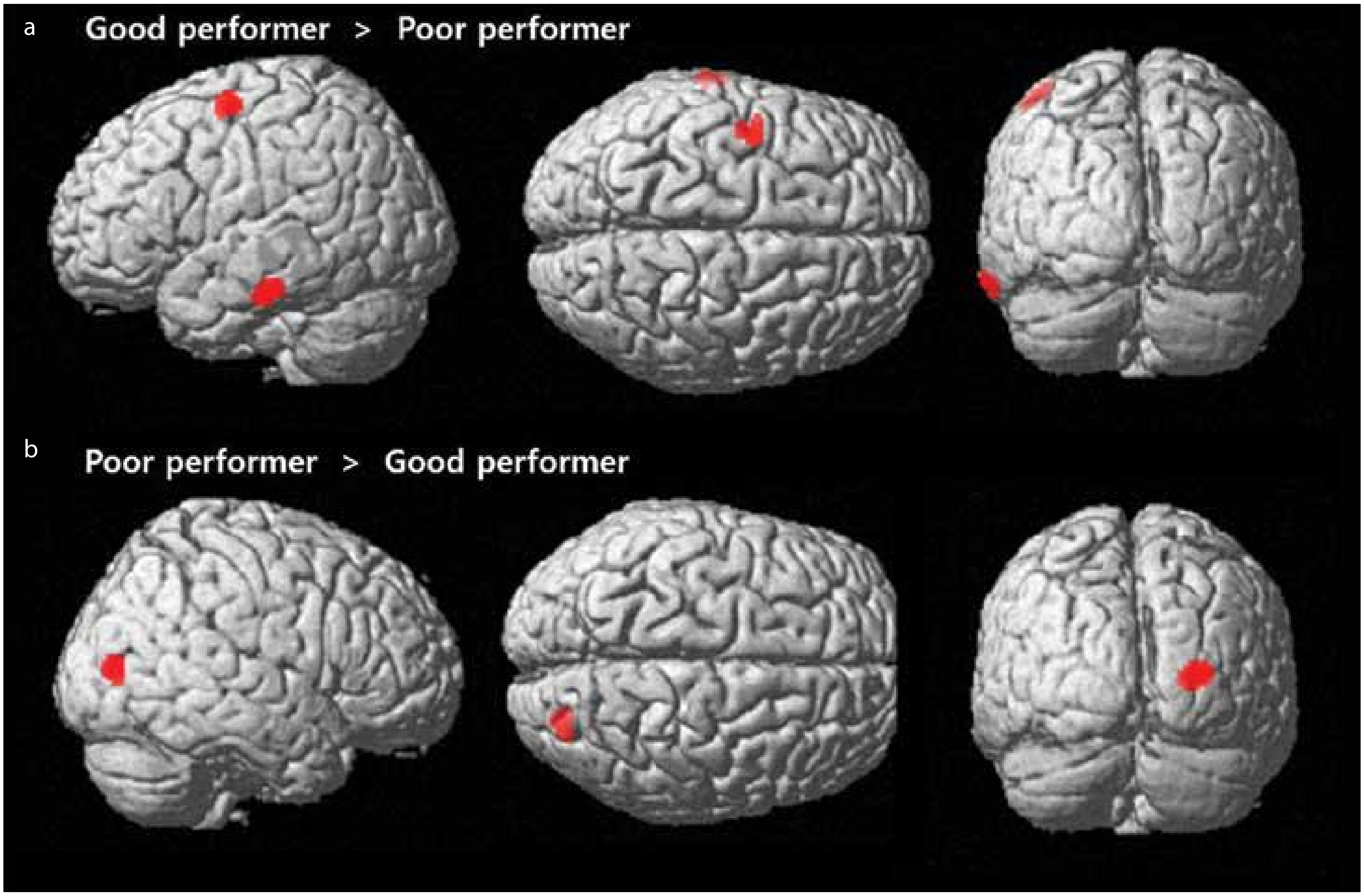

Figure 2. a, b. Preoperative PET comparison between good and poor performers. Deaf patients whose brain metabolism was higher in frontotemporal regions became good CI users (a), but those with higher metabolism in visual association areas became poor users (b)

DISCUSSION

There are several clinical predictive factors for speech perception ability in postlingual deaf subjects after CI. The duration of auditory deprivation is an important factor that is known to contribute to speech recognition in postlingual deaf adults [15]. As the duration of auditory deprivation increases in postlingual deaf subjects, the speech perception abilities of an individual with a cochlear implant decrease [16-22]. It seems that, as in prelingual deaf children, the period of auditory deprivation has a major effect on CI outcomes, with probably a different mechanism in play. In addition, pre-implant residual hearing may have a significant influence [23, 24]. Better residual hearing may be related to better CI outcomes. We compared preoperative clinical data that were known to be possible prognostic factors in elderly deaf patients. However, the known contributing clinical factors such as duration of deafness, residual hearing, and age at operation were not different between the two groups. This may indicate that known clinical factors cannot fully explain the variability in this group of elderly postlingual deaf patients. Other interacting factors such as brain plasticity may play an important role in the outcome of CI. Several studies have reported that cerebral plasticity may affect post-CI outcomes in postlingual deaf subjects [5, 25-27]. We also found a significant difference in hypermetabolic cortical areas between good performers and poor performers. Although this is not conclusive, it seems that the difference in hypermetabolic cortical areas that was demonstrated by FDG PET reflects a difference in cortical plasticity and may be one of the multifactorial reasons why the post-CI outcomes were different between the groups. However, it is not clear if brain plasticity is an independent prognostic factor. We believe that other predictive factors for outcomes such as residual hearing, age at operation, and duration of deafness affect plasticity and that a PET scan can be a biomarker of this multifactorial plasticity.

The reason why subjects with higher metabolism in frontotemporal regions became good CI users, whereas those with higher metabolism in visual association areas became poor users is unclear. It may be that dependence on visual information and cross-modal plasticity, which favors visual information processing, have a negative effect on auditory information processing after implantation. In order to successfully perceive auditory speech, integration of audiovisual inputs is known to be crucial [10, 11]. However, it seems that too much dependence on visual information before CI acts as an impediment. Although auditory–visual cross-modal plasticity is essential for overcoming limitations in auditory information, auditory processing is still the most important factor for auditory language performance. Higher metabolism in the visual cortex may represent an excessive bias toward visual information between auditory and visual processing. It has been postulated that greater dependency on the visual function performed by the occipito-temporal region due to auditory deprivation may interfere with the acquisition of auditory language [5]. Similarly, Sandmann et al. [28] reported a visual takeover type of reorganization in the auditory cortex of cochlear implant users and that the extent of this cross-modal reorganization was systematically related to speech recognition ability with a cochlear implant. In other words, visual processing dominance was inversely related to speech recognition ability with a cochlear implant. Little is known about cross-modal plasticity in the elderly but, if the same theory applies, elderly subjects with higher dependence on frontotemporal information processing may be more able to obtain restoration of auditory information from a CI device. Elderly subjects with higher dependence on visual information processing may have developed a cross-modal neural network that disregards auditory information and relies more on visual information. In these elderly subjects, the auditory cortex may not efficiently process auditory information even after restoration of auditory input by CI. We presume that higher metabolism in frontotemporal regions represents the remaining function and/or residue of auditory information processing, whereas higher metabolism in visual association areas before CI represents excessive compensation and cross-modal plasticity of the visual information processing network, which takes over the function of the preexisting auditory information processing network.

Another explanation is also possible for prefrontal cortex hypermetabolism. Similar results have been demonstrated by other researchers in younger deaf subjects; that is, increased left dorsolateral prefrontal cortex metabolism was related to excellent speech perception [5]. The prefrontal location of high glucose metabolism that was found in our study is nearly identical to the location demonstrated in the study by Lee et al [5]. It has been postulated that the dorsal cortex exhibits a correlation with general cognitive competency: general intelligence, working memory, and attention [5]. Also, the left prefrontal cortex may participate in semantic and phonological processing regardless of input modality [29-31]. Deaf subjects who rely more on the prefrontal cortex are expected to have a better outcome after CI due to better cognitive strategies (working memory and reasoning) [5]. This hypothesis may also apply to our elderly deaf subjects; that is, elderly subjects with better cognitive strategies may show a better CI outcome in the end.

To explain the discrepancy between the current study and previous studies, some limitations in our study should be mentioned. Our results are limited to the 1-year period after CI. Currently, little is known about the long-term outcomes of adult CI. Functional outcome and speech understanding should be studied in the long term in future studies. Our study only included 4 patients as poor performers and 11 patients as good performers. This small number was thought to be insufficient to show a strong statistical power but we found it very difficult to recruit patients with poor results. Most studies that reported a significant correlation between residual hearing and CI results used a speech sentence test to examine residual hearing ability, whereas we only used preoperative audiometry. Both audiometry and a speech sentence test are reasonable and robust methodologies to estimate residual hearing. Only one outcome parameter (CID) was analyzed as the outcome measure. As CID may not be a gold standard, reanalyzing the results with several different parameters may be needed for confirmation. Despite all these limitations, this study showed differences in hypermetabolic lesions to be a prognostic factor in elderly deaf patients following CI.

Cross-modal plasticity in elderly deaf patients when they are deprived of auditory input has an influence on speech perception ability following CI. This study revealed two cognitive traits of postlingual deaf elderly patients that predict CI outcomes: 1) deaf patients who are going to be poorer performers with a CI device maintain visual information processing during silent resting periods, and 2) other patients who recruited prefrontal modulation were predicted to show better speech outcomes.

Ethics Committee Approval: Ethics committee approval was received for this study from Institutional Review Board of Seoul National University Hospital for research involving human subjects (IRB No. C-0701-063-196).

Informed Consent: Written informed consent was obtained from the patient who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - S.H.O, S.O.C; Design - S.H.O, J.H.L, H.J.L, M.W.S., K.T.P.; Supervision - S.H.O., S.O.C.; Funding - S.H.O., S.O.C.; Materials - S.O.C., S.H.O., J.H.L., H.J.L, M.W.S., K.T.P.; Data Collection and/or Processing - H.J.L., S.H.O., J.H.L., H.J.L., M.W.S., K.T.P.; Analysis and/or Interpretation - J.H.L., H.J.L., M.W.S., K.T.P.; Literature Review - J.H.L., H.J.L., M.W.S., K.T.P.; Writing - J.H.L., H.J.L., M.W.S., K.T.P.; Critical Review - S.H.O., S.O.C.

Acknowledgement: This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2006-2005090).

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

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