International Journal of Pediatric Otorhinolaryngology 111 (2018) 170–173

Contents lists available at ScienceDirect

International Journal of Pediatric Otorhinolaryngology

journal homepage: www.elsevier.com/locate/ijporl

Electrical dynamic range is only weakly associated with auditory performance and speech recognition in long-term users of cochlear implants

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ARTICLE INFO

Keywords:
Cochlear implantation
Dynamic range
Speech performance
Consonant

ABSTRACT

Objective: The electrical dynamic range (EDR) has been suggested to be related to auditory performance in cochlear implant (CI) users. However, few reports have evaluated postlingual CI users who have used CIs for long periods in comparison with prelingual CI users. Here, we evaluated auditory perception and speech performance in terms of the EDR in long-term CI users. The EDR, and auditory and speech performances, were compared between pre- and post-lingual CI users.

Methods: We enrolled all patients who received CIs from April 2000 to December 2010 at Seoul National University Hospital, and who had ≥5 years of experience with CIs. The EDRs affording subjective responses at the threshold level (T-level) and comfortable level (C-level) were analyzed in terms of their relationships with pure tone audiometry levels, speech evaluation scores, including those on the Phonetically Balanced (PB) Word List test, vowel and consonant tests, a sentence test, and the Korean version of the Central Institute for the Deaf (K-CID) test; we also calculated Category in Auditory Performance (CAP) scores.

Results: We found no significant difference in the average EDR, CAP, K-CID, PB word, consonant, or vowel scores between pre- and post-lingual CI users. The EDR was weakly associated with the PB word ($P = 0.003$, $r = 0.462$) and consonant scores ($P = 0.005$, $r = 0.438$). Other speech evaluations, such as the CAP, K-CID, and vowel scores, were not significantly associated with the EDR T-level. We found no association between pure tone thresholds at 0.5, 1, or 2 kHz, and the speech evaluation scores or EDRs of low-, middle-, or high-frequency channels.

Conclusions: The EDR was only weakly associated with speech performance, such as scores on consonant and PB word tests in long-term CI users, irrespective of pre- or post-lingual deafness status.

1. Introduction

Individuals with normal hearing can process sounds over a range of 120 dB. However, the overall dynamic range of speech encompasses only some of this range, approximately 40–55 dB [1]. Cochlear implants (CIs) bypass sound amplification by the cochlea, directly stimulating the auditory nerve. A speech processor compresses acoustic stimuli, reducing the dynamic range (DR). The input DR is regarded as optimal over the range 50–60 dB, and determines the acoustic inputs mapped to the user's electrical dynamic range (EDR) [2–4]. Previous studies reported that the acoustical DR exerted a significant effect on speech recognition by CI users [5]. Early studies suggested that a DR of about 45 dB was necessary for optimal speech recognition [6].

Any effect of the EDR on auditory perception and speech performance remains unclear. Many studies have found that EDR compression exerted a significantly negative impact on speech recognition [5,7,8]. Perception of vowels and phonemes articulated in the presence of background noise is affected by the EDR. However, other studies suggested only mild effects of the EDR on auditory perception [9–11]. Most prior studies enrolled prelingual CI patients who did not exhibit good auditory performance during mapping and speech tests. Such confounders of poor cognition or perception in young CI patients render it difficult to evaluate the extent to which the EDR actually reflects auditory performance. In addition, few comparisons have been made between pre- and post-lingual CI patients in terms of how auditory performance is affected by the EDR. As electrical stimulation after CI placement evolves for at least 6 months after surgery, associations between the EDR and auditory performance should be investigated in

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https://doi.org/10.1016/j.ijporl.2018.06.016
Received 9 January 2018; Received in revised form 7 June 2018; Accepted 8 June 2018
Available online 12 June 2018
0165-5876/

patients with greater experience of CI use.

Here, was explored the effect of the EDR on auditory performance and speech perception in long-term CI users. All study subjects received identical CI devices (Nucleus implants). To ensure that the results were reliable, all enrolled patients were > 15 years of age and had ≥5 years of CI experience. Auditory perception and speech performance were evaluated by reference to the EDR. As auditory neural plasticity changes with longer duration of deafness, the patients were divided into pre- and post-lingual deafness groups before evaluating the effect of the EDR on auditory performance.

2. Materials and methods

2.1. Study population

This study was approved by the Institutional Review Board of Seoul National University Hospital. All patients who received CIs in from April 2000 to December 2010 were initially enrolled. Of these, users of Nucleus devices with ≥5 years of experience of CI use were finally enrolled. To ensure the reliability of speech evaluation tests and EDR assessment, we included only patients > 15 years of age. Exclusion criteria were the presence of any inner ear anomaly that could affect hearing performance (cochlear hypoplasia; a common cavity; incomplete partition of grades I or III; or/and a narrow bony cochlear nerve canal evident on temporal bone computed tomography and magnetic resonance imaging of the internal auditory canal). We also excluded patients with surgical complications and those for whom speech evaluation and EDR data were incomplete. Additionally, seven patients were excluded because they used CIs only occasionally. Four patients with prelingual deafness had initially used sign language or lip reading for communication, and received CIs only when aged 20–30 years. Similarly, three patients with postlingual deafness were only occasional users of CIs, and had not undergone any speech rehabilitation. Finally, we included 40 patients (22 pre- and 18 post-lingual). For each patient, we measured the EDR yielding a subjective response at the threshold level (T-level) and a comfortable level (C-level), and performed pure tone audiometry tests and speech evaluations.

2.2. Mapping strategies

The mapping strategies were identical for all patients (ACE, MP1 + 2; PW = 25, sensitivity = 12). For each patient, the T-level was the lowest current level (CL) eliciting an auditory sensation. The C-level was the highest CL that was not uncomfortably loud. The difference between the C- and T-level was the EDR. The electrical channels were divided into three groups: low-frequency (22–16), middle-frequency (15 − 8), and high-frequency (7–1).

The types of speech processors were Freedom for 23 patients, CP 810 for 8 patients, CP 910 for 10 patients, and 3G for 5 patients. There was no difference on the T-level, EDR, and speech performance and perception tests according to the types of speech processors.

2.3. Speech performance and perception

Pure tone audiometry data were collected at 0.5, 1, and 2 kHz (hearing thresholds; dB HL). Speech evaluation was done using the Phonetically Balanced (PB) Word List, vowel and consonant tests, and a sentence test [the Korean version of the Central Institute for the Deaf (K-CID) test]. The results of speech evaluations are presented as percentages (%). We also calculated Category in Auditory Performance (CAP) scores [12].

2.4. Statistical analysis

The correlations between EDR or T-level and K-CID, PB word, consonant, and vowel scores were analyzed using Pearson correlation test. Differences in speech performance and perception were evaluated in terms of the types of electrical channels (low- [22–16], middle- [15–8], or high-frequency [7–1] channels) using one-way analysis of variance (ANOVA) and the chi-squared test with the Rao-Scott correction. The two-tailed *t*-test was employed to compare the pre- and post-lingual groups; a P-value < 0.05 was considered to indicate significance. All analyses were performed using SPSS software (ver. 21.0; IBM Corp., Armonk, NY, USA).

Table 1
Comparison between prelingual and postlingual deaf subjects.

	Prelingual	Postlingual	P-value
Number	22	18	
ASM DR	51.90	53.08	0.74
ASV DR	9.69	7.05	0.16
T-level	144.11	141.84	0.73
PTA			
0.5 kHz	26.36	28.06	0.52
1 kHz	25.91	26.11	0.92
2 kHz	29.09	29.17	0.97
Average	27.12	27.78	0.72
K-CID	86.18	85.56	0.92
PB word	80.04	75.69	0.48
consonant	87.69	83.31	0.46
vowel	93.61	95.00	0.69
CAP	6.59	6.78	0.40

ASM DR; across-site mean dynamic range, SD; standard variation, T-level; threshold level, PTA; pure tone audiometry, KCID; Korean version of Central Institute for the Deaf, PB word; Phonetically Balanced word, CAP; Category in Auditory Performance.

3. Results

A total of 40 patients (22 pre- and 18 post-lingually deaf patients) were analyzed (Table 1). The mean patient age was 26.43 years. The average age of the prelingually deaf group was 19.3 years and that of the postlingually deaf group was 34.9 years. There were 18 male and 22 female patients. The average EDR was 52.94 CL and ranged from 23.68 to 79.95 CL. The average pure tone threshold was 27.79 dB HL. On speech evaluation, the mean CAP score was 6.37. The average extent of sentence perception, as measured using the K-CID score, was 75.48%. The mean PB word, consonant, and vowel scores were 69.25%, 80.58%, and 89.21%, respectively. We found no significant difference in the average EDR, CAP, K-CID, PB word, consonant, or vowel scores between patients with pre- and post-lingual deafness (Fig. 1). The EDR exhibited a weak correlation with the PB word (P = 0.003, r = 0.462) and consonant scores (P = 0.005, r = 0.438), but not with the K-CID or vowel scores (Fig. 2). The T-levels did not show significant correlation with EDR, K-CID, PB word, consonant, and vowel scores.

Subgroup analysis by the type of electrical channel evaluated, and the EDRs of low- (22–16), middle- (15 − 8), and high-frequency channels (7–1), did not show any correlations with the CAP, K-CID, PB word, consonant, or vowel scores. Inter-channel variations in the EDRs did not influence speech outcomes. We found no significant correlations between pure tone thresholds of 0.5, 1, and 2 k Hz, and the EDRs of low- (22–16), middle- (15 − 8), or high-frequency (7–1) channels. Although statistical significance was not attained, a trend toward a positive correlation was evident between the pure tone threshold at 0.5 kHz and the EDRs of low-frequency channels (P = 0.008, r = 0.26). No speech evaluation test (the CAP, K-CID, or PB word, vowel, or consonant tests) exhibited any significant relationship with the EDR of any frequency channel.

4. Discussion

We found weak associations between the EDR and PB word and consonant tests in long-term CI users. The T-level was not significantly