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ORIGINAL ARTICLE

Cochlear implant mapping strategy to solve difficulty in speech recognition

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Abstract

Background: Cochlear implants (CIs) are viable treatment options in patients with severe to profound hearing loss. Speech recognition difficulties were reported in some CI recipients even with a good-aided hearing threshold. The aim of this study was to report a mapping strategy based on different target-aided hearing thresholds to achieve optimal speech recognition and maximize functional outcomes. The safety and efficacy of the mapping strategy were also inspected in the article.

Methods: This prospective repeated measures study enrolled 20 adult CI recipients with postlingual deafness using the MED-EL CI system. Word and sentence discrimination assessment and administration of a questionnaire pertaining to comfort level were conducted at the end of each session. The electrophysiological features of the CI mapping were recorded.

Results: The correlation between audiometry results and word and sentence recognition was not high. CIs performed best at an audiometry threshold between 25 and 35 dB.

Conclusion: CI performance with the best perception relies on a balance between minimizing the hearing threshold and maximizing the dynamic range while maintaining an appropriate comfort level, which was achieved when the target hearing threshold was set at 25–35 dB in this study.

Keywords: Auditory perception; Auditory threshold; Cochlear implant; Electrophysiology; Speech perception

1. INTRODUCTION

Cochlear implants (CIs) have become a viable treatment in patients with severe to profound hearing loss.[1] After cochlear implantation the sound processor must be appropriately programmed and customized for the individual. Parameters of an electrical pattern generated by the internal device in response to sound stimulation must be determined following the CI.[2] For the MED-EL system, the minimal electrical stimulation responded to auditory inputs (THR) and the maximal tolerable currents of each electrode (MCL) are assessed during the fitting.[3] The collective set of parameters is referred to as a MAP. Several MAPs are tried during a fitting, to determine which MAP yields the best auditory perception.[2]

A major challenge when fitting CI systems lies in compressing the wide range of intensities present in acoustic input signals into the limited range that is available for electrical stimulation.[4] However, complications, such as headache, facial nerve stimulation, and unwilling noise, concurred with increased electrode currents.[5,6] In practice, CI recipients face difficulty in speech recognition even with brilliant audiometry hearing thresholds.[3,4,7] There are gaps between the electrophysiology parameters, hearing perception, and speech recognition,[8] and a solution for the difficulties does not exist currently.

To achieve optimal hearing discrimination, we conducted a study to evaluate the speech recognition function with different mapping strategies. The safety and availability of the strategies were also investigated.

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2. METHODS

2.1. Ethical considerations

The current study was approved by the research ethics committee of our facility (REC 106-17), and it was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all prospectively enrolled patients.

2.2. Participants

A total of 20 adult CI recipients with post-lingual deafness using the MED-EL CI system were enrolled from June 2017 to May 2018. All the participants had more than 2 years of experience with their devices and were full-time users, had stable stimulation levels in their sound processor MAPs, and were unilaterally implanted with MED-EL Standard electrode implant. The inclusion criteria were age 20–80 years, post-lingual deafness, having used the MED-EL CI system for more than 6 months, being a daily user, and using 12 electrodes. Considering the nature of difficulty in speech recognition despite the auditory threshold under CI, acoustic neuropathy was listed as an exclusion criterion. The other exclusion criteria were situations that would result in difficulty in CI mapping and interpretation of experiment results, including impaired cognitive function, and the presence of other neurological disorders.

2.3. Sound processor programs

The base set of stimulation levels used in each participant's MAP was measured using the recommended streamlined fitting procedure. All CI recipients were under MED-EL's speech processing strategy FS-4 (Innsbruck, Austria) in ordinary life and the speech processing strategy were remained unchanged throughout the study. MCLs and THRs were measured separately. MCL was set using an ascending technique that increased the currents until the participant reported that the sound was loud but still comfortable. THRs were set at the hearing threshold using Hughson-Westlake procedures under each session. The MAPs were then tested in 'live-mode', and whether the participant's voice or the tester's voice evoked any discomfort was checked.

2.4. Study design

A prospective, repeated measures single-subject design was used. After enrollment, a speech perception test was conducted before the adjustment of CI devices. Prior to entry of trial sessions, the CI recipient was mapped adherent to MED-EL protocol, which maintained THR not audible and kept THR level as 1/10 of MCL. The MCL would be adjusted according to the participant's feedback and was manipulated till desired aided auditory threshold was achieved, that is 15–25 dB. Mapping parameters were adjusted according to repeated sound field audiometry. MCL levels were determined and were remained unchanged during all the sessions.

Participants were evaluated over sessions 2 weeks apart and the mapping parameters would be tuned to the original setting during the period. In different sessions, mapping was performed by adjusting the THR to achieve the target-aided thresholds. Aided thresholds were measured in sound field audiometry using frequency-modulated (warble) tones at the octave frequencies between 250 Hz and 8000 Hz via a calibrated audiometer in a quiet sound booth. The sensitivity of CI was set at 75% and volume was set at 100% during sound field audiometry throughout the study.

Participant parameters were mapped via repeated sound field audiometry until target aided thresholds of 15–25, 25–35, and 35–45 dB were achieved in sessions A, B, and C, respectively. Each participant underwent a 2-week fitting period for each MAP determined in each session. A speech perception test was conducted at the end of each fitting period. Further mapping was aborted if the patient complained of tinnitus, unwanted noise, headache, or other discomforts during the program, and the fitting parameters acquired most recently before that point were utilized.

2.5. Speech perception test

All speech perception tests were conducted under the same protocol and by different speech pathologists randomly, who were blinded to the previous session. To eliminate the learning effect, same amount of examination was assigned to each speech pathologist and speech perception tests were undergone with the original voice of speech pathologist. A speech perception test was conducted under sound field audiometry booth, with the upper limit of target threshold add 50 dB, that was 75, 85, and 95 dB for sessions A, B and C, respectively. Hearing ability was measured with modified Mandarin speech perception mentioned in a previous article by Sun et al.[9] which comprised eight lists of 25 sentences and eight lists of 25 words. All of the sentences were familiar and widely used in daily life, they were phonetically balanced, and the targeted number of vowels, consonants, and tones within each list was initially calculated based on statistical distributions across 3500 commonly used Mandarin Chinese words. The sentence perception score was obtained as follows:

1. Eight versions of the sentence perception lists are chosen randomly.
2. There are 25 sentences in each list.
3. Each sentence contains 2 to 7 keywords.
4. The final result is presented as a percentage.
5. A total of 1 point is awarded for each correct keyword.
6. A monitored live voice (speech balanced at 0 dB on the volume unit) is used without lip reading.
7. An open-set format (with no options given to patients) is applied, and patients must repeat each sentence after it is finished.
8. The examination is executed under a mean aided threshold added 30 dB.

A single list of words and a single adaptive run of sentences were administered for each condition in each session.

2.6. Questionnaire

At the end of every session, participants were asked to complete a questionnaire at home. They rated their ability to hear and understand under a variety of listening situations, including in the car, inside their home, at a social gathering, and at the market, as well as their ability to hear and understand the content of news or movies on television. The questionnaire was based on a five-point scale (1 = poor and 5 = excellent), and participants circled the number corresponding to their rating for each session. Participants were also asked to rate how comfortably they heard the test stimuli in each session, and describe any specific discomfort they did encounter where applicable.

Data collection and analysis

Demographic data, including age, sex, and period of hearing deprivation, were obtained preoperatively. MAPs parameters, word and speech recognition scores, and questionnaire results and percentages derived from each session were recorded and analyzed. Data were analyzed via one-way repeated measures analysis of variance (ANOVA). SPSS version 20.0 (IBM Corp., Armonk, NY, USA) was used to assess the effects of different conditions, and the post-hoc Bonferroni test was used to compare conditions. $p < 0.05$ was deemed to indicate statistical significance.

3. RESULTS

3.1. Demographic features of the study population

Twenty-five patients with postlingual deafness who received unilateral MED-EL CI were recruited for the study. Only 20 patients were enrolled and underwent experiment sessions. The five excluded patients included three who declined to attend the program regularly and two who had auditory neuropathy. Total 12 males and eight females underwent the program. The mean age of implantation was 48.95 y (range, 25–83 y); the mean period of hearing deprivation was 14.5 y (range, 5–50 y). There were seven out of 20 participants (35%) who fell in the category of auditory threshold of 25–35 dB prior to the study. In addition, seven participants (35%) were in the category of 15–25 dB and six participants (30%) were in the category of 35–45 dB before the study. The participant numbers between each category were not different significantly.

Aided hearing thresholds in each session were confirmed before the speech perception test.

3.2. Speech perception test

The best performance in word recognition scores was recorded while the target sound field threshold was set at 25–35 dB (session B). Analyzed with one-way repeated measures ANOVA with post hoc Bonferroni test, word recognition scores measured in session B were 20.8% higher than those measured in session A ($p < 0.01$), and 33.4% higher than those measured in session C ($p = 0.014$).

The sentence recognition scores recorded in session B were 3.5% higher than those measured in session A (not statistically significant) and 37.8% higher than those measured in session C ($p < 0.01$).

In summary, the best result of word and sentence recognition occurred in session B, which targeted the hearing threshold at 25–35 dB rather than 15–25 dB.

Some of the participants were benefitted from shifting the aided threshold in speech perception. When stratified according to the original aided auditory threshold, improvement in word recognition function was observed in three participants (3/7, 42.8%) when aided threshold shifted from 15–25 dB (prior to trial) to 25–35 dB. On the other hand, improvement in word recognition was also noted in one participant (1/7, 14.3%) while aided threshold adjusted from 25–35 dB to 15–25 dB. In participants with the original aided auditory threshold at 35–45 dB, improvement was found in one recipient while shifting aided threshold to 25–35 dB and none of the participants got improvement when the aided auditory threshold was set at 15–25 dB.

In sentence recognition, improvements were observed in three participants (3/7, 42.8%) when aided threshold shifted from 15–25 dB (before trial) to 25–35 dB. Similar portion of participants (4/7, 57.1%) gained improvement in sentence recognition when the aided threshold was adjusted from 25–35 dB to 15–25 dB. In participants with the original aided auditory threshold at 35–45 dB, improvement in sentence recognition was found in 2 recipients (2/6, 33.3%) while shifting aided threshold to 25–35 dB and none of the participant got improvement when aided auditory threshold was set at 15–25 dB. When aided threshold was tuned to 35–45 dB, none of the participant improved in speech perception. None of difference in any stratification reached statistical significance.

The results of word and sentence recognition are summarized in Figs. 1 and 2, respectively.

3.3. Questionnaire

The comfort level and subjective auditory perception during each session were investigated using the questionnaire. Complications or symptoms under each session were also recorded. No cases of tinnitus, unwanted noise, or other discomfort were recorded.

With the elevation of THR level, the comfort level decreased simultaneously. The comfort level in session A was lower than the comfort levels in sessions B and C ($p < 0.01$). The result of comfort level is depicted in Fig. 3. Although there was a trend of decreased comfort level in session C compared to session B, the difference was not significant statistically.

In subjective hearing perception, the results between different situations were heterogeneous. Higher auditory perception in the car and at home under session B compared to session A and session C were recorded, $p < 0.05$ and 0.01, respectively. Although the trend of higher auditory perception at a social gathering and in the market under session B compared to the other 2 sessions was observed, the difference between the sessions was not significant statistically.

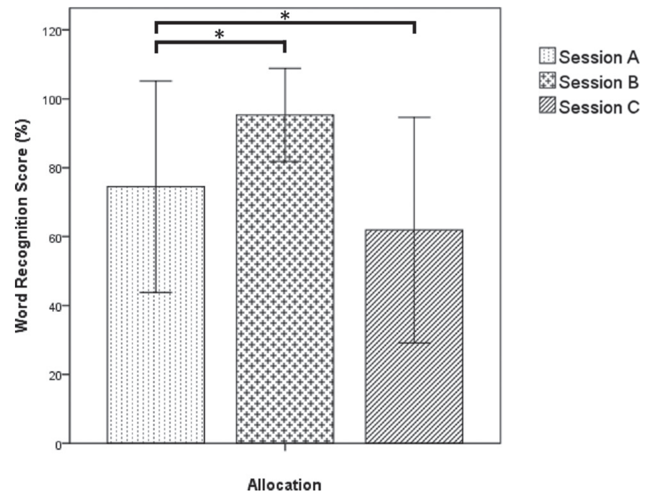

Fig. 1 Histogram showed mean word recognition score recorded in each sessions and range of 2 standard deviation (SD) was depicted over bar chart. The best result of word recognition was recorded in session B (25–35 dB) which was 20.8% and 33.4% higher than session A and C, respectively. Asterisk indicates significant difference.

Compromised in the ability to understand the content of news or movies on television was measured in session C, $p < 0.05$. A lower score was recorded in session A than in session B, 4.4 and 4.8, respectively, $p = 0.58$.

3.4. Electrophysiological parameters

MCL and THR were measured during every session and the dynamic range (DR) of the electrical stimulus was calculated, where DR = MCL – THR. MCL did not change significantly throughout the sessions. The highest THRs were recorded in session A (13.63 QU) followed by session B (4.89 QU) and then session C (1.98 QU). All the sessions differed significantly from each other ($p < 0.01$). The highest DRs were recorded in session C (26.2 QU), followed by session B (23.2 QU) and then session A (15.2 QU). In concordance with Busby and Arora,[8] there was 34.5% compression in session A compared to session B. In session C, 13.0% expansion in DR was observed compared to session B. The DRs in all sessions differed significantly from each other ($p < 0.01$) (Fig. 4).

4. DISCUSSION

In this study, we evaluated the effect of CI mapping with different target auditory threshold and its impact on speech perception, electric characteristic, and comfort level. We found improvement in speech recognition under the session of target auditory threshold at 25–35 dB rather than soft or very soft voice.

In a previous study conducted by Vaerenberg et al[3] on a global survey of mapping strategy revealed that mapping strategies vary across institutes. Most implant teams have an expert opinion of what the expected level of performance for an individual recipient should be, and more detailed adjustments are made. Although variability exists across CI centers, some common practices generally enrolled in each session of mapping include checking electrode impedance, presence of open or short circuit, threshold of audibility, upper tolerance limits for each electrode, and adjusting electric parameter if necessary.[4] Despite no congress, low auditory hearing threshold focus on soft voice or even very soft voice was a common target in daily practice. However, the target functional outcome in speech recognition was less documented.

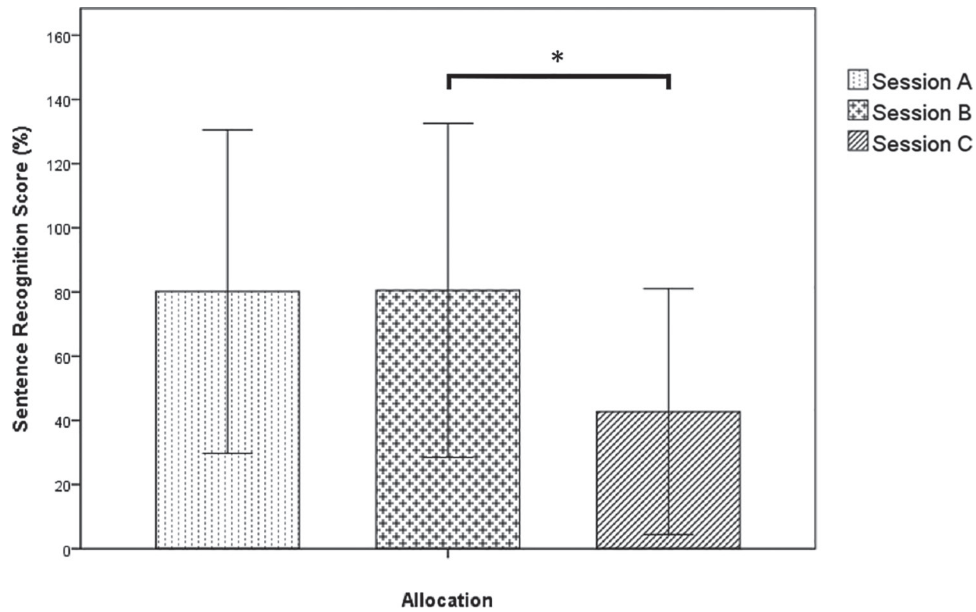

Fig. 2 The result of sentence recognition score recorded in each session. The best sentence recognition score was recorded in session B (25–35 dB). Sentence recognition score in session B was 3.5% and 37.8% higher than session A and C, respectively. Asterisk indicates significant difference.

In the study conducted by Busby and Arora[8] that investigated the effects of threshold adjustment on aided hearing thresholds and speech perception in adults using the Nucleus CI system (Cochlear Limited, Sydney, Australia), lower aided hearing thresholds could be achieved via elevated THR levels and consequence compressed DR. Considering the positive relationship between compressed DR and aided hearing threshold, no beneficial effects on the word or sentence recognition were observed. Interestingly, increased speech recognition function was observed in the group on lowering THR levels and expanded DR, and the aided hearing threshold was not violated until the THR level was lowered to achieve 30% DR expansion. This phenomenon could be attributed to special electrophysiological characteristics of the cochlea.[4,10,11] Stimulation to cochlear nerve consist of not only the intensity of electrical currents but also the change in the currents' intensity and spectral content and temporal content between currents.[7,10]

Appropriate stimulation dynamic ranges for speech recognition have been investigated; however, variation existed between studies.[11–13] Despite the difference in CI devices, processor, and methodology, wide dynamic range in signal input, and electric stimulation were requested to achieve adequate speech recognition in a previous study.[14]

Dynamic range expansion could be achieved either by elevated MCL levels or tuned down THR levels. With the elevation in the MCL level, the dynamic range for signal expression increased. However, considering electrode stability and discomfort resulting from excessive electric stimulation, the MCL level was not adjusted until 1 year following implantation.[3] Acceptance of

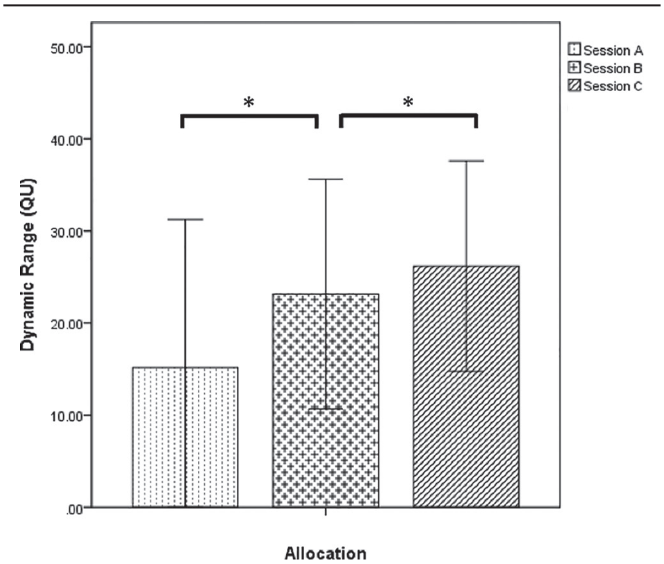

Fig. 3 Comfort level of cochlear implant (CI) fitting under each session. More comfortable experience of CI fitting was measured in session B and session C and subsequently in session A. Asterisk indicates significant difference.

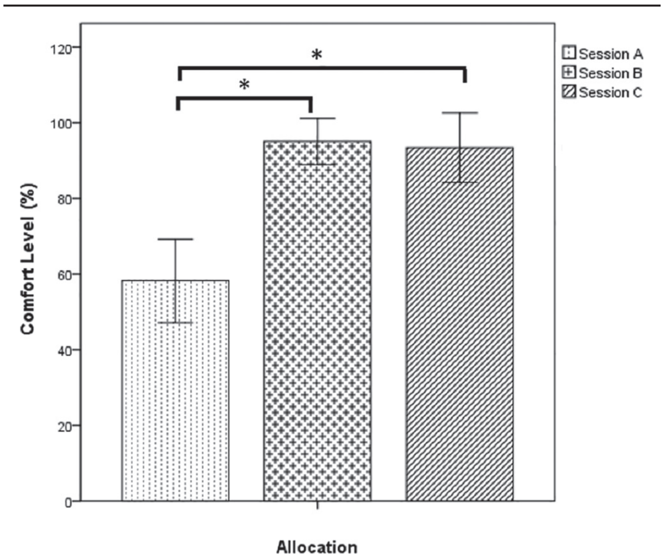

Fig. 4 Dynamic ranges (DR) under each session. As targeting audiometry threshold lowering, compression of dynamic range occurred. Change in the DR differed between session. Asterisk indicates significant difference.

Table 1

Demographic feature of participant.

Case number	Gender	Age at implant (y/o)	Hearing deprivation (yr)	Original auditory threshold (dB)	Etiology
1	Female	25	18	17.5	SLC26A4
2	Female	39	9	15	OTOF
3	Male	67	30	42	Unknown
4	Male	50	10	38.3	Unknown
5	Female	56	10	28	Unknown
6	Male	59	35	40	Unknown
7	Male	38	6	37.5	Unknown
8	Male	62	6	37.5	Unknown
9	Male	83	50	44.5	Unknown
10	Female	55	5	27.5	Unknown
11	Male	41	10	27.5	NPC
12	Male	31	17	22.2	GJB2
13	Male	28	20	17.5	m1555A>G
14	Female	52	6	33.3	Unknown
15	Female	43	8	27.5	m1555A>G
16	Male	58	9	22.5	NPC
17	Female	26	10	15	GJB2
18	Male	41	13	15	DFNB59
19	Female	64	8	28.3	NPC
20	Male	61	10	30	Unknown

The details of demographic feature of CI recipient, including gender, age, period of hearing deprivation, auditory threshold prior to this program and etiology of deafness. GJB2, OTOF, SLC26A4, DFNB59, m.1555A>G: deafness result from gene mutation.
NPC, nasopharyngeal carcinoma treated with conjunctional chemo-radiation therapy.
GJB2, OTOF, SLC26A4, DFNB59: GJB2, OTOF, SLC26A4, DFNB59 gene mutation.
m.1555A>G: mitochondrial DNA mutation, 1555 A>G.

electric stimulation differed from participant to participant and the cerebral plasticity that underwent during the process. It took a long period for the participants to tolerate the electric stimulation and dynamic range expansion.

On the other hand, tuning down the THR level rarely caused discomfort and could expand DR immediately. In previous studies, discomfort due to unwanted environmental noise only occurred when the THR level exceeded 10% of the maximal comfortable level.[15] Although expanded electric dynamic range and increment in speech recognition were recorded during tuned down THR level resulted in the increased aided hearing threshold, decrement in aided threshold and speech recognition did not occur until DR expansion 30%.[8]

The symphysis between electric stimulation and auditory perception was complicated and the effect of adjustment of the THR level on hearing perception vary across studies.[8,13,16–18] Predicting aided hearing threshold by managing THR alone was difficult. Aided hearing threshold shifting from 19.2 dB to 23.3 dB was recorded in a previous study when DR expanded 30%,[8] whereas DR compression 34.5%, while shifting aided hearing threshold from 25–35 dB to 15–25 dB was measured in this study. Changes in the DR differed between each session and it was difficult to predict the functional outcome; thus, it was more reasonable to titrate the THR level according to the target hearing threshold to gain DR rather than tuning the THR alone. Instead of applying target aided hearing threshold at 15–25 dB, shifting the target aided hearing threshold to 25–35 dB experienced an increment in speech recognition and comfort level. Elevating the target aided hearing threshold to 25–35 dB was safe and effective in gaining adequate DR and increasing speech recognition.

In addition to objective behavioral auditory examinations, subjective feedback from each mapping session is worthy of consideration. Various questionnaires have been applied to investigate different aspects of CI mapping outcomes.[4,15,19] To focus on the subjective hearing ability under various conditions and comfort levels across the sessions, the questionnaire was modified and translated into Chinese in the current study. On increasing the threshold current and minimizing the hearing threshold (session A), a comparatively lower comfort level was observed. A balance between the comfort level and hearing performance was achieved in session B. Conversely, the 'best experience of daily use' scores were recorded by the participants in session B via the questionnaire. It is reasonable to infer that the best CI performance relies on a balance between minimizing the hearing threshold and maximizing DR, which simultaneously maintains an appropriate comfort level that was achieved via a set target hearing threshold at 25–35 dB in this study.

Methodological considerations

According to the result of this study, it was safe, comfortable, and effective to expand DR by elevating the target auditory threshold. However, the performance of CI was determined by multiple factors. Methods such as a program to increase input signal dynamic range,[15] deactivation of electrodes to gain signal resolution between electric stimulation,[20] and delayed signal input between electrodes to improve signal temporal resolution[10] were documented to improve CI performance. The interaction between the parameters is complicated and further multivariate study to improve CI recipients' speech recognition is warranted.

Although trends result from shifting aided auditory threshold in each stratification were observed, the differences were not significant statistically. Heterogeneity in response to adjustment between subjects and limited case number in each subgroup might contribute to the result. Further study with a large sample size is warranted.

In conclusion, on investigating the CI mapping strategy with different target thresholds, the best speech recognition performance was observed while the target threshold was set between 25 and 35 dB. With elevated target threshold, extended DR and improved speech recognition were observed. The best perception relies on a balance between minimizing the hearing threshold and maximizing the DR, which simultaneously maintains an appropriate speech recognition. In this study, the best perception was achieved while target aided hearing threshold was set at 25–35 dB.

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