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Investigating the use of spread of excitation as a measure of sensitivity to interaural asymmetry

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ABSTRACT

Interaural asymmetry decreases sensitivity to binaural cues such as interaural time differences (ITD) for bilateral cochlear implant users. However, the effects of interaural asymmetry may be mitigated for this population by the broad current spread typical of electrical stimulation. Current spread can be estimated using spread of excitation (SOE) functions. These measure the extent to which electrodes stimulate overlapping neural populations. This is done by measuring electrically evoked compound action potentials (eCAPs) in response to stimulating different masker electrodes. The goal of this study was to determine if SOE functions can predict the effect of interaural asymmetry on cochlear implant users' ITD thresholds. SOE functions were measured for multiple probe electrodes across the array. Participants also completed an ITD detection task that measured the ITD thresholds for different interaural electrode pairs. The preliminary results suggest that eCAPs may not be directly predictive of the effect of asymmetry on ITD sensitivity, but they may offer insight into the minimum interaural asymmetry that will affect ITD sensitivity. Future studies will investigate the relationship between SOE and other binaural cues, such as interaural level differences.

Keywords: interaural asymmetry, bilateral cochlear implants, interaural time differences

1. INTRODUCTION

While bilateral cochlear implants (CIs) provide benefits over unilateral CIs (1), bilateral CI users do not receive the same binaural hearing benefits as normal hearing listeners do. For example, bilateral CI users receive minimal or no benefits from interaural time differences (ITDs; 2,3), an essential binaural cue that allows listeners to localize sound sources. One reason for this is that interaural asymmetry, when electrodes in the left and right CIs stimulate mismatched cochlear locations, is both prevalent (4) and decreases sensitivity to binaural cues like ITDs (5–8). However, the effect of that asymmetry may be reduced given the broad spread of current typical with CIs. As a result of the broad range of neurons in the region surrounding an electrode being excited with such current spread, it is likely that there are some matched locations in the two ears that are stimulated even when the stimulated electrodes are centered on different locations in the two ears. Thus, a broader current spread may reduce the negative effects of interaural asymmetry.

One way of measuring the broadness of the current spread is to measure electrically evoked compound action potentials (eCAPs). By spatially separating masker and probe stimulation along the array, it is possible to measure the spread of excitation (SOE), reflecting current spread. The goal of this study was to test the hypothesis that the extent of the SOE, as measured by eCAPs, predicts the effect of interaural asymmetry on ITD sensitivity. To do this, ITD thresholds were calculated while holding an electrode in one ear constant and varying the electrode used in the comparison ear. Additionally, eCAP SOEs were measured using a variety of masker electrode locations in the comparison ear.

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2. Methods

2.1 Participants

Six bilateral CI users, all using Cochlear brand devices, were tested. Participant details are provided in Table 1.

Table 1 – Participant Information

Subject Number	Age (years)	Duration Implant Use (Left)	Duration Implant Use (Right)
I59	53	4 years	6 years
I64	71	15 years	16 years
I65	66	5 years	6 years
I66	56	1 week	5 years
I68	63	5 years	6 months
I69	61	1 year	1 year

2.2 Stimulation Parameters for ITD Thresholds

Stimulation was controlled by the Nucleus Implant Communicator (NIC3) and the RF Generator (Cochlear). Electrodes were stimulated with 500-ms pulse trains with a pulse rate of 100 pulses per second (pps), a phase duration of 32 µs, and an interphase gap of 8 µs.

After measuring threshold (T) and maximum comfort (C) levels, stimulation levels were loudness balanced to minimize the potential confounding factor of loudness differences. Loudness balancing was conducted at the most comfortable loudness level (MCL), indicated by participants as a six on a ten-point scale. Loudness balancing was conducted both within each array and across arrays. For within-array loudness balancing, groups of four adjacent electrodes were stimulated in sequence using 500-ms pulse trains with a 1-s interstimulus interval. The stimulation level was adjusted by the experimenter by adjusting C levels for any electrode that the participant indicated was louder or softer than the level of the first electrode stimulated in the group. Adjustments were typically in 1 current level (CL) step. After all electrodes in that group were loudness balanced, the next group of four adjacent electrodes was stimulated. The first electrode from the new group was the same as the last electrode from the previous group (e.g., group 1: electrodes 1–4; group 2: electrodes 4–7).

For across-array loudness balancing, electrode 11 was used for each array and stimulation alternated between the two ears. The stimulation consisted of 500-ms pulse trains with an interstimulus interval of approximately 500 ms, presented at MCL. The percent of the dynamic range used for stimulation was adjusted based on the reported loudness of the target compared with the reference stimulation. Once balanced, the percent of the dynamic range for each ear that yielded matched loudness for the MCL stimuli was used for all electrodes in a given ear.

2.3 Measuring ITD Sensitivity

To measure the subjects' ITD thresholds, electrode 11 was used as the electrode in the reference ear. This was typically the right ear unless there were deactivated electrodes in the left ear. The stimulus in the reference ear was paired with different electrodes in the comparison ear. Typically, all electrodes in the comparison ear were used across the trials. Participants were presented with a four-interval, two-alternative, forced-choice task. On a computer monitor, participants viewed four boxes that corresponded with each stimulus. The first and last stimulus had an ITD of 0 and could not be chosen. Participants were asked to choose which of the middle two stimuli perceptually differed from the other three stimuli. This target stimulus was always the only stimulus with a non-zero ITD. The button corresponding to the correct answer turned green after each trial. The subsequent stimuli were presented directly after the participants answered.

Testing used a descending protocol. Participants started with an ITD of 4000 µs, which was increased if the ITD of the first stimulus was not suprathreshold. Each ITD was presented twice before the ITD was decreased. ITD was decreased by 2 dB nine times (20 stimuli per block), regardless of whether responses were correct or incorrect (see Figure 1). Scores were calculated as the percent correct across all trials in the block. Participants completed a practice block that was identical to the actual test before starting this task.

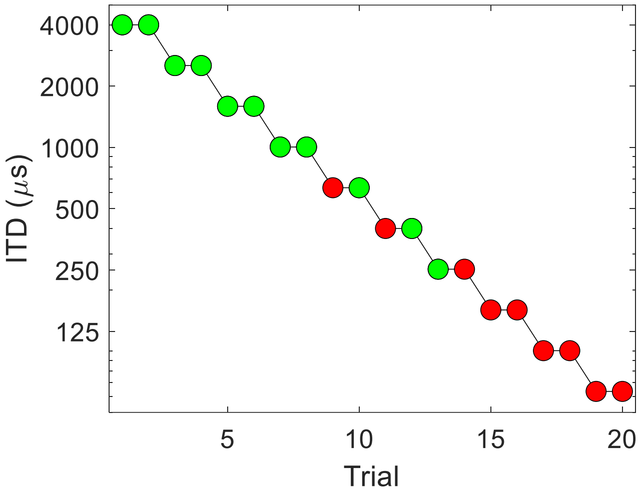

Figure 1 - Example of one run of the descending protocol. Each circle indicates one trial. Green circles indicate correct responses and red circles indicate incorrect responses.

2.4 Stimulation Parameters for Measuring Spread of Excitation

The comparison ear from the ITD task was used for measuring SOE. Stimulation consisted of symmetrical biphasic pulses with a 25-µs pulse phase duration and a 7-µs interphase gap. One participant was tested with a 50-µs phase duration due to voltage compliance limitations with the shorter pulse. The default probe rate of 80 Hz and 400-µs masker-probe interval were used. The stimulation mode was set to MP1. For recording parameters, the recording mode was set to MP2. eCAPs were averaged over 50 sweeps with a measurement window of 1600 µs and a 20-kHz sampling rate.

2.5 Measuring Spread of Excitation

To measure SOE, impedances were first measured to ensure that no electrodes had short or open circuits. Maximum Acceptable Levels were then measured across the array by stimulating each electrode initially with 100 CL stimulation, and then increasing stimulation using a step size of 5 CL for each sweep. Participants rated the loudness on a ten-point scale and indicated when the stimulation was at the maximum acceptable level (a rating of 8) if they were to listen to the same stimulus for ten-minutes.

eCAP SOE was recorded for each subject using the Advanced Neural Response Telemetry feature built into the Nucleus Custom Sound EP 6.0 software. SOE was measured across the array for odd-numbered electrodes (see Figure 2). To remove stimulus artifacts, the standard forward-masking subtraction technique was used, as outlined in previous studies (9). Four conditions were used. In the first condition, only a probe pulse was delivered using the target electrode, causing both the eCAP and system artifacts to be recorded. In the second condition, a masker was delivered using a given electrode, causing the neurons in the surrounding area to enter a refractory period. After each masker pulse, a probe pulse was delivered using the target electrode. This occurs after the masker-probe interval**.** In the third condition, only the masker is delivered. Finally, in the fourth condition, a zero-amplitude probe stimulus was used. This process was repeated for different maskers, which included all odd-numbered electrodes, except for the recording electrode, as well as electrodes 2 and 22. The combined results of these conditions were used to calculate the SOE.

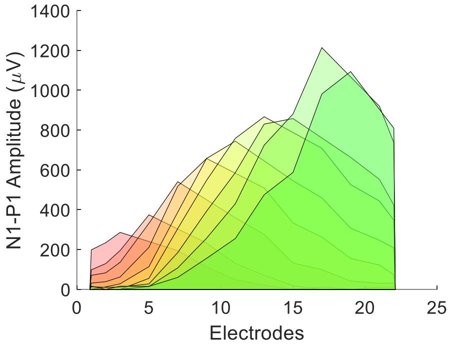

Figure 2 - Example of eCAP SOE functions across the array for subject I64. Each colored shape indicates the SOE function for a different probe electrode, with red shading indicating a more basal electrode and green shading indicating a more apical electrode.

3. Results

For each subject, normalized SOE and the normalized ITD functions were plotted together for comparison (Figure 3). The probe electrode for the SOE function was chosen based on the peak of the ITD function. All ITD thresholds at and below 50% (chance) were set to 50% prior to normalizing the ITD function. The area under the curve was calculated both for the normalized SOE and the normalized ITD functions for each subject. The areas under the curve for each measure were directly compared (Figure 3). Analysis of the preliminary results did not reveal a significant relationship between the area under the ITD function and the area under the SOE function (r = 0.12; 95% confidence interval: -0.26 to 0.96; see Figure 4), although this may reflect low power given the small sample size. Additionally, for all cases but I65, the normalized area under the curve for eCAPs was smaller than that for ITDs, which suggests that the effect of interaural mismatch on ITD functions includes factors beyond what is reflected by the physiological SOE.

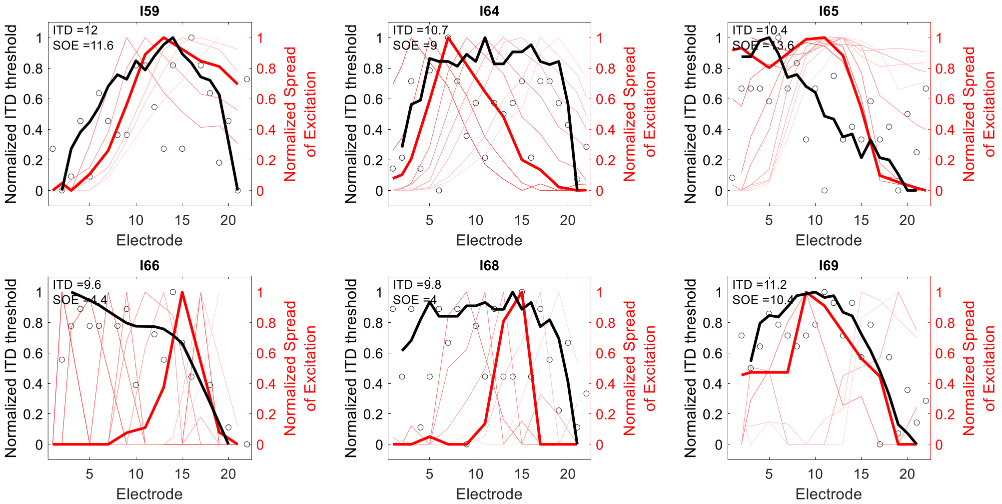

Figure 3 - Comparative graphs of normalized ITD thresholds (black circles/line) and normalized eCAP SOE (red lines). The bold red line indicates the SOE function with a probe at approximately the peak of the ITD function. The area under the curve for each of the ITD and SOE functions are given in each panel.

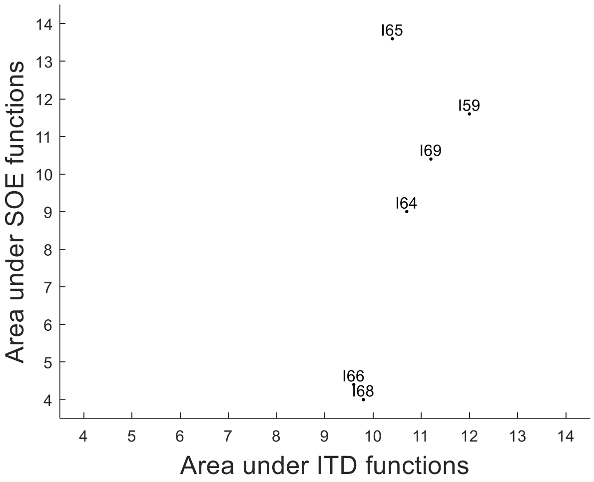

Figure 4 – Within-subject comparison between the area under the ITD function and the area under the SOE function

4. Discussion

This study aimed to investigate whether eCAPs can help predict the effect of interaural asymmetry on ITD sensitivity for bilateral CI users. The preliminary results indicated that SOE functions did not predict ITD functions, although the area under the SOE functions was typically smaller than the area under the ITD functions. This may suggest that SOE sets a lower limit for the effects of interaural asymmetry, while other factors further along the auditory pathway also influence the effect of such asymmetries.

The data were normalized to remove between-subject variance in absolute eCAP amplitude. This could potentially affect the relationship between SOE and the effects of interaural asymmetry on ITD sensitivity. Some participants had very small eCAPs, raising the possibility that the area under the curve was underestimated for these participants because eCAPs for many stimuli were below the level of detectability, although this would not be apparent with normalized functions. This possible confound will need to be investigated in the future.

While the current study investigated the role of SOE on the effects of interaural asymmetry on ITD thresholds, this only measures the peripheral effects of current spread within the target ear. Since ITD thresholds reflect brainstem processing (7), it is possible that the signal is further transformed as it ascends the auditory pathway, altering the relationship between interaural asymmetry and ITD thresholds. Additionally, it is possible that the SOE of stimulation in the contralateral ear also is affecting that relationship. That would be consistent with previous research indicating that broadness of contralateral masking is affected by the broadness of the current spread of the masker (10).

Another key finding of the current experiment is that, while the upper range of the area under the curve was similar for both ITDs and SOEs, the lower range was dramatically different, with the smallest area under the curve for ITD thresholds being over twice as large as the smallest area under the curve for the SOE. This may suggest that SOE sets the lower limit for the effects of interaural asymmetry on ITD thresholds. Alternatively, it may indicate that there is a more complex relationship between SOEs and ITD thresholds.

5. Conclusion

Although eCAPs do not appear to be directly predictive of the effect of asymmetry on ITD sensitivity, they may offer insight into the minimum interaural asymmetry that will affect ITD sensitivity for a given CI user. There may be other relationships between interaural asymmetry and SOE for other binaural cues such as interaural level differences and for other binaural tasks such as binaural fusion. As with ITDs, for a more complete picture of the relationship with SOE, information gathered further along the auditory pathway and/or from the contralateral ear may be necessary.

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REFERENCES

1. Dunn CC, Tyler RS, Witt S, Ji H, Gantz BJ. Sequential bilateral cochlear implantation: speech perception and localization pre- and post-second cochlear implantation. Am J Audiol. 2012;21(2):181–9.
2. Aronoff JM, Freed DJ, Fisher LM, Pal I, Soli SD. Cochlear implant patients' localization using interaural level differences exceeds that of untrained normal hearing listeners. J Acoust Soc Am. 2012 May;131(5):EL382–7.
3. Seeber BU, Fastl H. Localization cues with bilateral cochlear implants. J Acoust Soc Am. 2008 Feb;123(2):1030–42.
4. Aronoff JM, Padilla M, Stelmach J, Landsberger DMDM. Clinically Paired Electrodes Are Often Not Perceived as Pitch Matched. Trends in Hearing. 2016;20:1–9.
5. Kan A, Stoelb C, Litovsky RY, Goupell MJ. Effect of mismatched place-of-stimulation on binaural fusion and lateralization in bilateral cochlear-implant users. Journal of the Acoustical Society of America. 2013;134(4):2923–36.
6. Poon BB, Eddington DK, Noel V, Colburn HS. Sensitivity to interaural time difference with bilateral cochlear implants: Development over time and effect of interaural electrode spacing. J Acoust Soc Am. 2009/07/31. 2009;126(2):806–15.
7. Hu H, Dietz M. Comparison of Interaural Electrode Pairing Methods for Bilateral Cochlear Implants. Trends in Hearing. 2015;19.
8. Staisloff HE, Aronoff JM. Comparing Methods for Pairing Electrodes Across Ears With Cochlear Implants. Ear Hear. 2021 Feb;42(5):1218–27.
9. Abbas PJ, Hughes ML, Brown CJ, Miller CA, South H. Channel interaction in cochlear implant users evaluated using the electrically evoked compound action potential. Audiol Neurootol. 2004;9(4):203–13.
10. Lee DH, Aronoff JM. Changing stimulation patterns can change the broadness of contralateral masking functions for bilateral cochlear implant users. Hearing Research. 2018 Jun;363:55–61.