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Frequency-to-Place Mismatch Impacts Cochlear Implant Quality of Life, But Not Speech Recognition

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Objective: To retrospectively compare frequency-place mismatch among adult cochlear implant (CI) recipients with lateral wall (LW) and perimodiolar/Mid Scala (PM/MS) arrays, and to quantify the impact of these factors on early post-activation (3 months) speech recognition abilities and CI-specific quality of life.

Methods: One hundred and twenty-six adult participants were separated into two groups: (1) 83 participants who underwent CI with a PM/MS array and 43 patients who underwent CI with a LW array. All participants completed the Cochlear Implant Quality of Life Profile (CIQOL-35 Profile) instrument. Angular insertion depth and semitone mismatch, which contribute to frequency-place mismatch, were assessed using post-operative CT scans. Word and speech recognition in quiet were determined using the Consonant-Nucleus-Consonant (CNC) and the AzBio tests, respectively ($n = 82$ patients).

Results: LW arrays were more deeply inserted and exhibited less semitone mismatch compared to PM/MS arrays. No significant relationship was found between semitone mismatch and early post-operative speech perception scores for either PM/MS or LW arrays. However, greater degrees of semitone mismatch were associated with lower CIQOL-35 profile scores for PM/MS arrays.

Conclusions and Relevance: The results of this study indicate that both the degree of frequency-place mismatch, and its impact on CI-specific quality of life, vary by CI array design.

Key Words: cochlear implant outcomes, cochlear implant quality of life, frequency-to-place mismatch, speech recognition.

Level of Evidence: 4

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INTRODUCTION

Hearing outcomes are known to be highly variable among adult cochlear implant (CI) recipients.[1,2] In addition to duration of deafness and residual cochlear function, the spatial position of a CI electrode array can be an important determinant of speech recognition abilities after implantation.[3–5] The spatial positioning of a CI array depends upon both the cochlear anatomy of the recipient (cochlear size and cochlear duct length) and the physical form of the array itself. For example, lateral wall (LW) arrays are designed to sit along the outer wall of the cochlear duct within the scala tympani (ST), whereas pre-coiled perimodiolar (PM) electrodes are designed to assume a more medial position with the ST, in close juxtaposition to the cochlear modiolus where spiral ganglion (SG) cells are found.

Differences in device design and recipient cochlear anatomy lead to variations in angular insertion depth (AID), which has shown to be an important predictor of long-term speech recognition outcomes with a CI.[6,7] Differences in AID may impact hearing outcomes after CI by producing mismatches between the frequency range of speech information transmitted by the processor and the estimated SG frequency (semitone mismatch). These spatial discrepancies between the patterning of electrical stimulation by the CI array and the native tonotopic organization of the cochlea are also known as frequency-place mismatch.[8] This mismatch can produce spectral shifts in speech information relative to cochlear tonotopicity, which may compress and/or distort spectral and temporal information delivered to the brain and limit speech recognition abilities.[9]

Interestingly, the degree to which AID and frequency-place mismatch impact speech recognition abilities after CI appears to vary by CI array type. Whereas several studies of straight LW arrays have shown improvements in speech recognition outcomes with increasing AID,[5,6,10–12] other studies that included both LW and PM arrays have shown decrements in performance with deeper insertions.[13,14] The relative impact of AID and frequency-place mismatch on speech recognition abilities after CI for LW versus PM arrays remains to be determined, particularly in a time period soon after initial activation. Additionally, speech recognition outcomes after CI are often not correlated with patient-reported quality-of-life (QOL) measures and the impact of insertion depth and frequency-to-place mismatch on CI-specific quality of life is unknown.[15,16]

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In this study, we measured and compared electrode insertion angle and semitone mismatch among adult CI recipients with a variety of LW and PM arrays. We then quantified the impact of these factors on early post-activation (3 months) speech recognition abilities and on CI-specific quality of life measures using the Cochlear Implant Quality of Life-35 Profile (CIQOL-35 Profile) instrument. We focused on an early time period post-activation, given that most previous studies have focused on one-year post-activation data. We hypothesized that there would be an inverse relationship between the degree of frequency-place mismatch and CIQOL-35 Profile scores.

METHODS

Patients

This retrospective study was approved by our University's Institutional Review Board, and informed consent was not required. The study population consisted of 126 adult patients (≥ 18 years) with post-lingual hearing loss who underwent cochlear implantation between 2018 and 2021 and who underwent post-operative CT imaging which is standard clinical care at our institution. Inclusion criteria were documented history of post-lingual onset hearing loss, age of 18 years or older at the time of implantation, and available CT data to calculate AID. Exclusion criteria were revision CI, implantation for single-sided deafness, patients with extracochlear electrodes, and history of retrocochlear pathology. In addition, patients were required to have CNC word, AzBio Quiet, or CIQOL data at the 3-month post-activation time interval. Fifteen of the 126 patients included in the analysis were bilaterally implanted at the time of data collection.

CIs from three different manufacturers (Cochlear American [CA], Med El [ME], and Advanced Bionics [AB]) were evaluated in this study. The following arrays were represented in the study sample. From AB, the HiRes Ultra 3D HiFocus Mid Scala array was used. From CA, the CI512, CI522, CI612, CI622 and CI632 arrays were used. From ME, the Synchrony Flex 28 array was used. Electrode choice was personalized for each patient based on discussions with patient and surgeon preference. Patients were separated into two cohorts: (1) patients who received a pre-curved PM/MS array (PM/MS) and (2) patients who received a straight LW array.

Frequency-Place Mismatch

Frequency-place mismatch has been defined differently in the existing literature. To draw comparisons with these previous studies, two measures of frequency-place mismatch were evaluated in the current study. All participants were fitted with standard clinical programming methods using the default frequency alignments for each company.

Angular insertion depth. AID was assessed in a standard fashion using post-operative CT scans and previously published algorithms that define the relative locations of the cochlear modiolus, round window, and individual electrode contacts.[17–22]

Semitone mismatch/frequency place mismatch. To maintain consistency with published data, the semitone mismatch was calculated using methods described previously by Canfarotta et al.[6,7] The methods used here were explained in detail in previous studies and replicated here. Briefly, a fourth-order polynomial function was fit to the frequency-to-place mismatch as a function of the AID for each ear. The frequency-to-place mismatch was converted to semitone deviation at 1500 Hz (estimated to be an important frequency for alignment according to SG tonotopicity based on vocoder studies).[23]

Audiological Data

Speech recognition scores measured separately for each ear were obtained from our adult cochlear implantation patient database. Speech recognition scores included CNC words and AzBio sentences in quiet (AZBio Quiet). For pre-operative testing reported, speech recognition scores reflect performance in the ear to be implanted with hearing aids fitted to National Acoustics Laboratory-NL2 (NAL-NL2) targets.[24] For post-operative testing reported, speech recognition scores reflect performance in the implanted ear only. Speech recognition testing was performed in a sound-treated room in the sound field with speech presented at 60 dB SPL (0 degrees azimuth). None of the patients had significant residual hearing in the implanted ear; in other words, none used an acoustic component and none of the participants had low-frequency residual hearing sufficient to aid in sound field speech recognition tasks. If appreciable residual hearing was observed in the contralateral ear, then the ear was sufficiently plugged and/or muffed per standard clinical protocol.

Cochlear Implant Quality of Life

Self-reported functional abilities were assessed using the Cochlear Implant Quality of Life Profile (CIQOL-35 Profile).[25] The CIQOL-35 Profile is an established, well-validated, and psychometrically validated instrument that measures domain-specific QOL across six domains (communication, emotional, entertainment, environmental, listening effort, and social) and a global score. Scores for all domains and global measure range from 0 (low) to 100 (high).

Statistical Analysis

Analyses were performed in R statistical software and in GraphPrism 9 (San Diego, CA).[26] Nominal variables were

TABLE I.
Patient Demographics.

Variable	n_{Total} (%) 126 (100)	$n_{PM/MS}$ (%) 83 (65.8)	n_{LW} (%) 43 (34.2)	95% CI
Manufacturer				
Advanced bionics	32 (25.4)	27 (21.4)	5 (4.0)	
Cochlear	88 (69.8)	56 (44.4)	32 (25.4)	
Med-EL	6 (4.8)	0 (0)	6 (4.8)	
Sex				
Male	65 (51.6)	37 (44.6)	28 (65.1)	
Female	61 (48.4)	46 (55.4)	15 (34.9)	
Age at CI (years)	67.3 (±14.3)	67.1 (±14.8)	67.7 (±13.4)	[−4.7, 6.0]
Duration of HL (years)	26.4 (±17.4)	27.3 (±17.6)	24.6 (±16.9)	[−9.2, 3.9]
Insertion angle (degree)	420.8 (±78.1)	398.4 (±67.4)	464.2 (±79.6)	[39.2, 92.6]
Semitone mismatch	−8.6 (±6.5)	−10.5 (±5.5)	−4.8 (±6.5)	[3.5, 7.9]

Note: 95% CI = 95% CI for difference between means for PM/MS and LW.
Abbreviations: LW, lateral wall; PM/MS, Perimodiolar/MidScala.

Variable	x̄ (±SD) PM/MS	x̄ (±SD) LW	Total
CNC			
Pre-op (%)	9.2 (13.8)	17.2 (16.7)	12.0 (15.3)
3-month post (%)	48.9 (23.8)	50.0 (22.9)	49.2 (23.4)
Change (%)	38.8 (23.8)	30.4 (27.3)	35.9 (25.2)
AZBio quiet			
Pre-op (%)	10.8 (18.2)	26.6 (24.2)	16.3 (21.8)
3-month post (%)	57.7 (27.1)	60.3 (26.6)	58.4 (26.8)
Change (%)	47.1 (29.0)	26.4 (34.8)	40.3 (32.4)

TABLE II.
Speech Recognition Scores 3 months Post-Activation.

Abbreviations: LW, lateral wall; PM/MS, Perimodiolar/MidScala; x̄ (±SD), mean ± standard deviation.

summarized by frequency and percentage. Comparisons were performed using Chi-square analyses and Fischer Exact tests where statistically appropriate. Continuous variables were tested for normal distribution as determined by Kolmogorov–Smirnov tests. Comparisons were performed with student's *t*-tests. Predictive relationships between continuous variables were assessed with linear regression analyses. A statistical significance level was set to $p < 0.05$.

RESULTS

Patient Characteristics

Demographic data are outlined in Table I. The study population consisted of 126 adult patients (≥ 18 years) with post-lingual hearing loss who underwent cochlear implantation with devices from each of the three major implant manufacturers (*Advanced Bionics* = 32, *Cochlear* = 88, *Med-El* = 6). Implant array types included both PM/MS ($n = 83$ patients, 65.8%) and LW ($n = 43$ patients, 34.2%) designs. The mean age at the time of implantation was 67.3 ± 14.3 years and was comparable between patients who received PM/MS electrodes (67.1 ± 14.8 years) and LW electrodes (67.7 ± 13.4 years) (Table I). The study population was 51.6% male, and the mean duration of hearing loss was 26.4 ± 17.4 years (Table I). The duration of hearing loss was similar between patients who received PM/MS electrodes (27.3 ± 17.6 years). and LW electrodes (24.6 ± 16.9 years).

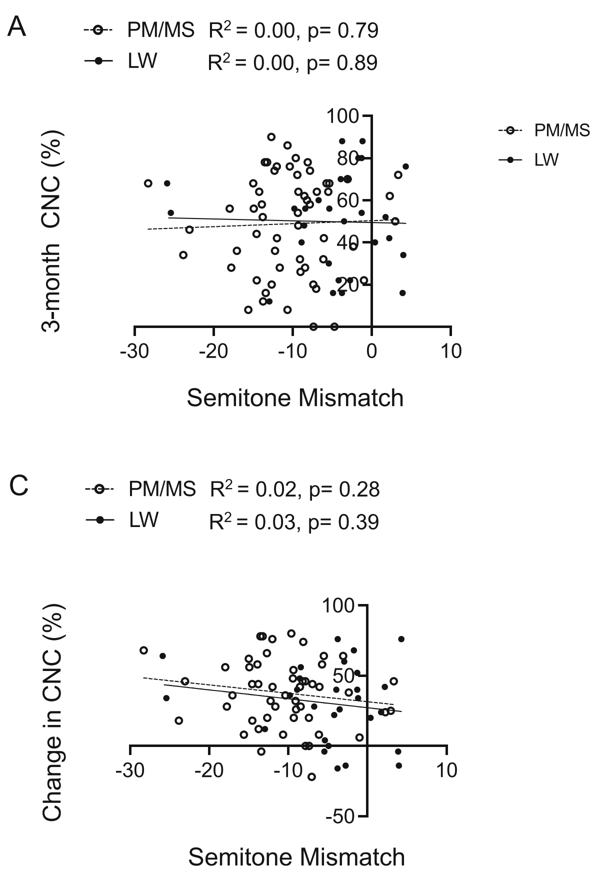

Fig. 1. Speech Recognition Score Improvement Is Not Predicted by Semitone Mismatch. (A) CNC scores (%) 3-month post-activation plotted as function of semitone mismatch. Linear regression lines shown by solid (LW) and broken (PM/MS) lines. (B) AzBio Quiet scores (%) scores 3-month post-activation plotted as function of semitone mismatch. Linear regression lines shown by solid (LW) and broken (PM/MS) lines. (C) Change in CNC scores (%) from pre-implantation to 3 months post-activation plotted as a function of semitone mismatch. Linear regression lines shown by solid (LW) and broken (PM/MS) lines. (D) Change in AzBio Quiet scores (%) from pre-implantation to 3 months post-activation plotted as a function of semitone mismatch. Linear regression lines shown by solid (LW) and broken (PM/MS) lines.

Implant Array Characteristics

There was significant heterogeneity in terms of the AIDs measured across CI arrays (range = 269.4°–619.1°). The mean AID for LW electrodes was substantially greater than for PM/MS arrays ($t = 4.8$, 95% CI of mean difference [39.2, 92.6], $n = 126$, student's t test) (Table I). There was also significant heterogeneity in terms of semitone mismatch across CI arrays (−28.3–4.3). The degree of semitone mismatch was less for LW electrodes compared to PM/MS arrays ($t = 5.2$, 95% CI of mean difference [3.5, 7.9], $n = 126$, student's t test) (Table I). Thus, compared to PM/MS arrays, LW arrays were more deeply inserted and exhibited less semitone mismatch.

Early Speech Recognition Performance after CI

Pre-operative speech recognition scores differed between PM/MS and LW arrays, with PM/MS arrays showing lower baseline CNC word scores (PM/MS = 9.2 ± 13.8% vs. LW = 17.2 ± 16.7%, $p = 0.006$, student's t-test) and AZBio Quiet sentence scores (PM/MS = 10.8 ± 18.3% vs. LW = 26.6 ± 24.2%, $p < 0.0001$, student's t-test) compared to LW arrays. To control for differences in pre-operative speech recognition scores when comparing post-operative performance levels, we opted to analyze post-operative scores in two ways: (1) comparing absolute post-operative speech recognition scores between groups and (2) comparing the "degree of change" in speech recognition scores between groups (3-month post-operative score minus pre-operative score).

Speech recognition scores substantially increased 3 months post-activation for both the PM/MS and the LW groups (Table II). CNC word scores increased for both PM/MS and LW arrays and there were no significant differences between groups in terms of either absolute post-operative CNC word scores ($t = 0.18$, 95% CI of mean difference of absolute 3-month score [−9.8, 11.8], $n = 82$, student's t test) or the degree of improvement ($t = 1.5$, 95% CI of mean difference of 3-month change [−20.1, 3.1], $n = 82$, student's t test). Similarly, AZBio Quiet scores increased for both PM/MS and LW arrays and there were no significant differences between groups in terms of absolute post-operative AZBio scores ($t = 0.42$, 95% CI of mean difference of absolute 3-month score [−9.6, 14.8], $n = 82$, student's t test). However, the *degree* of improvement in AZBio scores was greater for the PM/MS group ($t = 2.9$, 95% CI of mean difference of 3-month change [−34.9, −6.4], $n = 82$, student's t test) (Table II).

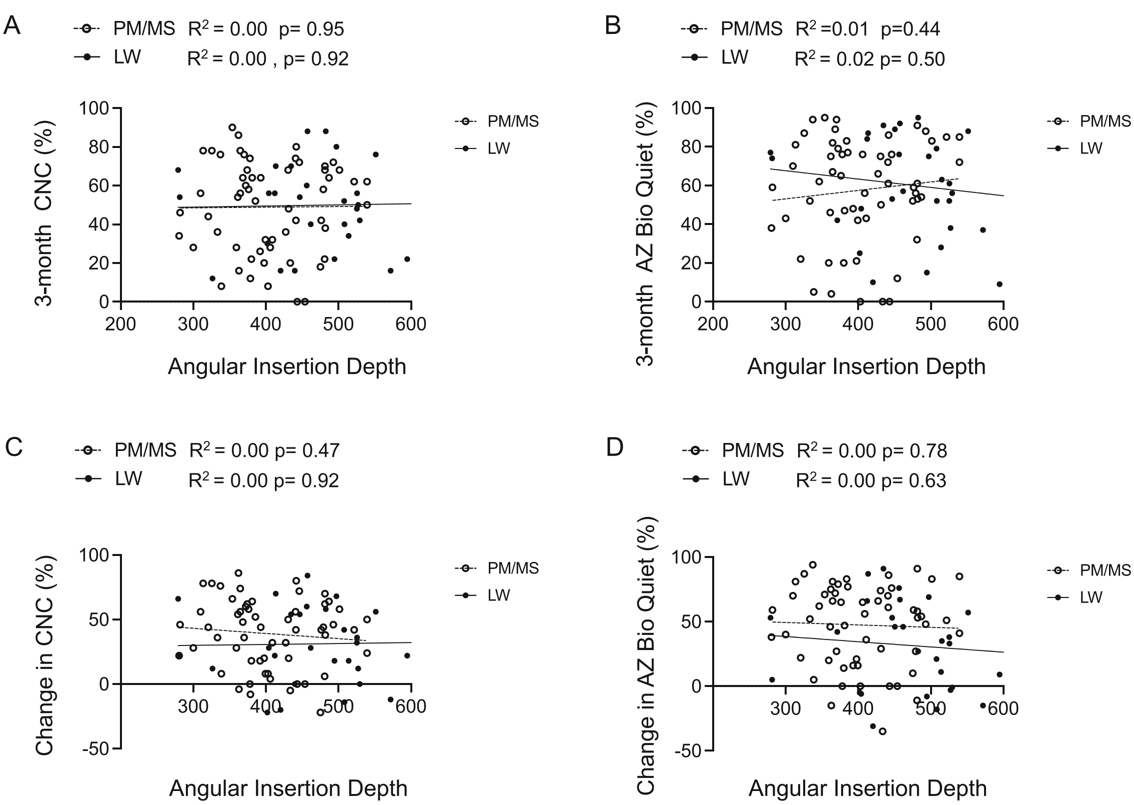

Fig. 2. Speech Recognition Score Improvement Is Not Predicted by Angular Insertion Depth (AID). (A) CNC scores (%) 3-month post-activation plotted as function of AID. Linear regression lines shown by solid (LW) and broken (PM/MS) lines. (B) AzBio Quiet scores (%) scores 3-month post-activation plotted as function of AID. Linear regression lines shown by solid (LW) and broken (PM/MS) lines. (C) Change in CNC scores (%) from pre-implantation to 3 months post-activation plotted as a function of AID. Linear regression lines shown by solid (LW) and broken (PM/MS) lines. (D) Change in AzBio Quiet scores (%) from pre-implantation to 3 months post-activation plotted as a function of AID. Linear regression lines shown by solid (LW) and broken (PM/MS) lines.

TABLE III. CIQOL-35 Profile Scores 3 Months Post-Activation.			
CIQOL-35 domain	x̄ (±SD) PM/MS	x̄ (±SD) LW	x̄ (±SD) Total
Global	48.3 (9.6)	49.3 (8.6)	48.6 (9.2)
Communication	45.4 (10.9)	44.9 (9.4)	45.3 (10.4)
Emotional	58.0 (15.3)	59.2 (17.2)	58.3 (15.7)
Entertainment	53.0 (19.2)	52.0 (18.5)	52.7 (18.9)
Environment	52.7 (16.3)	55.0 (11.3)	53.3 (15.0)
Listening effort	36.8 (13.0)	37.3 (11.5)	37.0 (12.5)
Social	59.6 (18.1)	62.1 (22.3)	60.4 (19.3)

Abbreviations: LW, lateral wall; PM/MS, Perimodiolar/MidScala; x̄ (±SD), mean ± standard deviation.

Speech Recognition and Frequency Place Mismatch

There was a significant positive association between semitone mismatch and AID when considered across array types ($R^2 = 0.59$, $p < 0.001$, $n = 125$, linear regression). This positive association was also present for PM/MS ($R^2 = 0.49$, $p < 0.0001$, $n = 82$, linear regression) and LW ($R^2 = 0.56$, $p < 0.0001$, $n = 43$, linear regression) arrays when considered separately.

Semitone mismatch was not associated with speech recognition performance 3 months post-activation (Fig. 1). No significant relationship was found between absolute CNC word scores 3 months after activation and semitone mismatch for either PM/MS ($R = 0.00$, $p = 0.79$, $n = 54$, linear regression) or LW arrays ($R = 0.00$, $p = 0.89$, $n = 28$, linear regression) (Fig. 1A). Similarly, no significant relationship was found between absolute AzBio Quiet scores 3 months after activation and semitone mismatch for either PM/MS ($R^2 = 0.02$, $p = 0.35$, $n = 54$, linear regression) or LW electrodes ($R^2 = 0.00$, $p = 0.64$, $n = 28$, linear regression) (Fig. 1B). There was also no relationship between 3-month *improvement* in CNC word scores (e.g., change scores) and semitone mismatch for either PM/MS ($R^2 = 0.02$, $p = 0.28$, $n = 54$, linear regression) or LW arrays ($R^2 = 0.03$, $p = 0.39$, $n = 28$, linear regression) (Fig. 1C). Similarly, no significant relationship was found between 3-month improvement in AzBio Quiet scores and semitone mismatch for either PM/MS ($R^2 = 0.00$, $p = 0.54$, $n = 54$, linear regression) or LW electrodes ($R^2 = 0.01$, $p = 0.56$, $n = 28$, linear regression) (Fig. 1D).

A similar analysis of speech recognition scores according to AID revealed that AID was not associated with speech recognition performance 3 months post-activation (Fig. 2). No significant relationship was found between absolute CNC word scores 3 months after activation and AID for either PM/MS ($R = 0.00$, $p = 0.95$, $n = 54$, linear regression) or LW arrays ($R = 0.00$, $p = 0.92$, $n = 28$, linear regression) (Fig. 2A). Similarly, no significant relationship was found between absolute AzBio Quiet scores 3 months after activation and AID for either PM/MS ($R^2 = 0.01$, $p = 0.44$, $n = 54$, linear regression) or LW electrodes ($R^2 = 0.02$, $p = 0.50$, $n = 28$, linear regression) (Fig. 2B). There was also no relationship between 3-month *improvement* in CNC word scores (e.g., change scores) and AID for either PM/MS ($R^2 = 0.00$, $p = 0.47$, $n = 54$, linear regression) or LW arrays ($R^2 = 0.00$, $p = 0.92$, $n = 28$, linear regression) (Fig. 2C). Similarly, no significant relationship was found between 3-month improvement in AzBio Quiet scores and AID for either PM/MS ($R^2 = 0.00$, $p = 0.78$, $n = 54$, linear regression) or LW electrodes ($R^2 = 0.00$, $p = 0.63$, $n = 28$, linear regression) (Fig. 2D).

Cochlear Implant Quality of Life

CIQOL-35 Profile domain scores from 3-months post-activation are shown in Table III. There were no significant differences in mean post-operative CIQOL-35 Profile domain scores between the PM/MS and LW groups. However, there was a significant association between CIQOL-35 Profile domain scores and the degree of semitone mismatch (Table IV). The results of simple linear regression analysis of CIQOL-35 Profile subdomain scores as a function of semitone mismatch are shown in Table IV. CIQOL-35 Profile scores in the Global, Communication, Emotional, Entertainment,

TABLE IV. Associations Between Semitone Mismatch and CIQOL-35 Profile Scores 3 Months Post-Activation.			
CIQOL-35 domain	R^2 (*p* value) PM/MS	R^2 (*p* value) LW	R^2 (*p* value) Total
Global	**0.23 (0.0007)**	0.18 (0.06)	**0.17 (0.0006)**
Communication	**0.15 (0.006)**	0.20 (0.05)	**0.10 (0.008)**
Emotional	**0.14 (0.009)**	0.12 (0.13)	**0.08 (0.02)**
Entertainment	**0.17 (0.004)**	0.01 (0.64)	**0.08 (0.02)**
Environment	0.04 (0.17)	0.07 (0.27)	0.04 (0.08)
Listening effort	0.08 (0.06)	0.17 (0.07)	**0.07 (0.04)**
Social	**0.14 (0.01)**	0.02 (0.58)	**0.08 (0.02)**

Note: Bolded regression coefficients and *p* values are statistically significant.
Abbreviations: LW, lateral wall; PM/MS, Perimodiolar/Lateral Wall; R2, simple regression coefficient.

TABLE V. Associations Between AID and CIQOL-35 Profile Scores 3 Months Post-Activation.			
CIQOL-35 domain	R^2 (*p* value) PM/MS	R^2 (*p* value) LW	R^2 (*p* value) Total
Global	**0.21 (0.001)**	0.09 (0.20)	**0.15 (0.001)**
Communication	**0.14 (0.008)**	0.09 (0.70)	**0.09 (0.01)**
Emotional	0.08 (0.055)	0.12 (0.13)	**0.07 (0.03)**
Entertainment	**0.10 (0.039)**	0.01 (0.70)	0.05 (0.08)
Environment	0.07 (0.069)	0.02 (0.58)	0.06 (0.05)
Listening effort	**0.13 (0.014)**	0.12 (0.14)	**0.10 (0.008)**
Social	**0.13 (0.015)**	0.02 (0.58)	**0.08 (0.02)**

Note: Bolded regression coefficients and *p* values are statistically significant.
Abbreviations: LW, lateral wall; PM/MS, Perimodiolar/Lateral Wall; R2, simple regression coefficient.

Listening Effort, and Social domains were inversely related to the degree of frequency-to-place mismatch (Table IV). When accounting for array type, these relationships between CIQOL-35 Profile scores and semitone mismatch were seen for PM/MS arrays but not for LW arrays (Table IV). This array-specific relationship was also seen between CIQOL-35 Profile scores and AID (Table V). Thus, while frequency-to-place mismatch was not predictive of early speech recognition scores, it was related to self-reported functional abilities.

DISCUSSION

Hearing outcomes and self-reported real-world abilities after cochlear implantation are variable and difficult to predict. Variation in the physical design of CI arrays impacts their post-implantation location within the ST, which can determine the spatial match between the patterning of electrical stimulation from the CI array and the native tonotopic organization of the cochlea. Previous studies describing the relationship between the spatial positioning of CI arrays within the cochlea and post-operative hearing outcomes have yielded mixed results.[5,6,10–14] The current study explored the impact of frequency-place mismatch on early post-operative hearing outcomes across several PM/MS and LW electrode arrays. We report that while associations between frequency-place mismatch and speech recognition scores were weak, there was a significant relationship between frequency-place mismatch and patient-reported outcome measures of CI-specific QOL.

Angular Insertion Depth and Frequency-Place Mismatch

In this study, we found that compared to PM/MS arrays, LW arrays exhibited greater insertion angles and relatively less semitone mismatch (Table I). Consistent with prior studies, we also found substantial variation in AID and semitone mismatch between patients both within and between the PM/MS and LW groups.[6] It is unsurprising that lower levels of semitone mismatch were seen for the LW group, given that these long, straight electrodes are inserted more deeply.

Early Speech Recognition and Frequency Place Mismatch

We found that CNC word scores and AZBio Quiet sentence scores increased substantially in the first 3 months after implantation across array types. The observation that AZBio sentence scores increased more precipitously for PM/MS arrays than for LW arrays is consistent with recent work that has shown an early advantage for PM arrays compared to LW arrays in terms of speech recognition scores in the first 6 months after implantation.[4] However, it should also be acknowledged that baseline AZBio sentence scores for PM/MS arrays were lower compared to LW arrays. This difference in baseline sentence scores may also explain the difference in change scores seen in groups, especially since absolute 3-month post-activation scores were similar between groups (Table II).

However, we found no relationship between early speech recognition scores and semitone mismatch or AID for either PM/MS or LW arrays (Figs. 1 and 2). These findings contradict several prior studies that have reported significant relationships between AID, frequency-place mismatch, and early hearing outcomes after cochlear implantation. For example, Canfarotta et al., showed that compared to shallow insertions, deeper insertions of LW arrays reduced frequency-to-place mismatch, which correlated with better CNC scores during the first 6 months of device use.[7] Similarly, Mertens et al., reported a linear negative correlation between the degree of frequency-to-place mismatch of LW arrays and speech perception in noise scores 6 months after CI activation.[27] It is important to note that these prior studies specifically reported findings for LW arrays, and that their sample sizes for LW arrays were relatively larger than in our current study. The correlation strengths reported in these prior studies were moderate (r range = 0.33–0.4), and our study may have been underpowered to detect such subtle relationships. In contrast to these previous studies, the current study examined electrode arrays from several manufacturers, some not intended to be as deeply inserted as LW arrays used in previous studies. This difference could also help to account for discrepancies in findings. Finally, the current study focused on a time interval sooner to activation, while other studies typically focused on outcome data at least 6 months post-activation. It is possible that other unknown factors are more important for early speech understanding outcomes, while frequency mismatch is more important with increased CI experience. Nevertheless, we report no substantive relationship between early post-activation speech recognition improvement scores and frequency-place mismatch for PM/MS or LW arrays.

Frequency-Place Mismatch, Angular Insertion Depth, and Cochlear Implant Quality of Life

We found significant relationships between semitone mismatch, AID and domain-specific CIQOL-35 Profile scores 3 months after CI activation. When considered as a single sample (PM/MS and LW combined), we found a significant inverse association between the degree of semitone mismatch and 3-month post-activation CIQOL-35 Profile scores in the Global, Communication, Emotional, Entertainment, Listening Effort, and Social domains (Table IV). This was also the case for AID and 3-month post-activation CIQOL-35 Profiles scores in the Global, Communication, Emotional, Listening Effort, and Social domains (Table V). Interestingly, upon sub-group analysis, we found that both semitone mismatch and AID were associated with CIQOL-35 Profile scores for patients with PM/MS arrays, but not LW arrays (Tables IV and V). In summary, for PM/MS arrays, greater degrees of semitone mismatch and shallower insertion depths were associated with lower levels of self-reported CI-specific quality of life.

Why was frequency-place mismatch associated with CI-specific quality of life but not with speech recognition scores? It is well established that speech recognition tests have poor ecological validity and incompletely represent the real-world experiences of CI users.[15,16] Therefore, while no associations were found between frequency-place mismatch and speech recognition abilities measured in a controlled environment (i.e., sound attenuated booth), it nevertheless appears that frequency-place mismatch had a real-world impact on the day to day experiences of CI users, and in particular, those with PM/MS arrays. It is possible that in the sonically complex contexts encountered in real-world listening environments, spectral shifts produced by frequency-place mismatch have an increasingly noticeable impact on the neural processing of speech information. This could theoretically lead to a more negative impact on CI-specific quality of life measures compared to speech recognition scores measured in the audio booth.

It is uncertain why there was an association between frequency-place mismatch and CI quality of life for PM/MS, but not, LW arrays. One possibility is that CI-specific quality of life may improve on different time scales post-activation for PM/MS and LW arrays. In the current study, we only report data from 3 months post-activation, and it is possible that at this time point, the full impact of LW arrays on CIQOL-35 profile scores is yet to be realized. It is also important to note that pre-implantation speech perception scores (CNC and AZBio scores) tended to be lower for PM/MS arrays compared to LW arrays (Table II), and this may have modulated the impact of post-implantation frequency-place mismatch on CI-specific quality of life. Finally, PM/MS arrays exhibited a smaller mean AID and a greater mean semitone mismatch compared to PM/MS arrays, which may have contributed to differences in CI-specific quality of life.

Study Limitations

This study had several important limitations. Firstly, the retrospective nature of the study limits the strength of conclusions that can be made. At our institution, one of five surgeons is given the opportunity to choose an implant array from each of the three CI manufacturers based on individual factors that are not uniform across surgeons. We did not prospectively randomize array selection and therefore could not control for potential confounding biases introduced at the time of array selection. This could have perhaps contributed to why baseline differences in speech recognition scores were seen between participants in the PM/MS and LW groups. A second limitation was the lack of available post-operative speech recognition data and CIQOL-35 Profile score data. A third consideration is the limited range of semitone mismatch seen in the LW group, which may have limited our ability to detect effects in the CIQOL-35 Profile score data. In the future, we hope that larger, prospectively studied data sets will provide valuable additional information.

CONCLUSION

The current study explored the relationship between frequency-place mismatch and early hearing outcomes after cochlear implantation for several implant array designs. While associations between frequency-place mismatch and speech perception scores were weak for both electrode types, we found a significant association between frequency-place mismatch and CI-specific quality of life for patients who received PM/MS arrays. Further research will be required to demonstrate how these relationships evolve over time post-implantation.

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