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Performance of cochlear implant recipients based on acoustic hearing level pre-cochlear implant

Haley A. Bruce
Washington University School of Medicine in St. Louis

PERFORMANCE OF COCHLEAR IMPLANT RECIPIENTS BASED ON ACOUSTIC HEARING LEVEL PRE-COCHLEAR IMPLANT

by

Haley A. Bruce

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Approved by:
Lisa G. Potts, Ph.D., Capstone Project Advisor
Noël Dwyer, Au.D., Capstone Project Advisor

Abstract: The aim of the study was to evaluate speech recognition performance in cochlear implant (CI) recipients with varying degrees of pre-CI hearing levels and determine the timeline to reach best performance.

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Table of Contents

List of Tables and Figures

INTRODUCTION

Multichannel cochlear implant (CI) usage has grown worldwide. As of December 2012, over 300,000 people have received a CI with almost 100,000 of these in the United States (National Institute on Deafness and Other Communication Disorders, 2014). The first U.S. Food and Drug Administration (FDA) approval of CI device systems in 1984 recommended candidacy to comprise post-lingually deafened adults with bilateral profound sensorineural hearing loss and no perceived benefit from hearing aids (Mudry & Mills, 2013; NIH). Technology advancements and improved performance by CI recipients over time has led to changes in CI candidacy criteria to include individuals with greater degrees of acoustic hearing and better speech recognition (Gantz, Turner, Gfeller, & Lowder, 2005; Krueger et al., 2008). Current FDA guidelines for adults have expanded candidacy to bilateral moderate to profound sensorineural hearing loss ≥ 70 dB HL and limited benefit from appropriately fit hearing aids, as measured by open-set sentence recognition scores ≤ 60% in the best aided condition (Franko-Tobin, Camilon, Camposeo, Holcomb, & Meyer, 2015; Zwolan 2009). Recommendations for open-set sentence recognition in the ear to be implanted vary by manufacturer. Cochlear and Advanced Bionics propose CI candidates score ≤ 50% in the best-aided condition, while Med El advises scores no greater than 50% in the best-aided condition. Medicare criteria deem necessary a bilateral moderate to profound sensorineural hearing loss with speech recognition scores ≤ 40% in the best-aided condition (Centers for Medicare & Medicaid Services, 2015). In 2014 the FDA approved the Cochlear Hybrid, a system with a shorter electrode array designed to preserve low-frequency residual hearing. This approval further expanded criteria to include CI candidates with normal to moderate hearing loss at low frequencies, and severe-to-profound hearing loss at mid and high frequencies. Individuals scoring between 10 - 60% on open-set word recognition in the

ear to be implanted meet the criteria (U.S. Food and Drug Administration, 2014). As a result, CI recipients meeting previous or older inclusion criterion (severe-to-profound audiometric thresholds) are now often labeled as traditional CI candidates (Plant, McDermott, van Hoesel, Dawson, & Cowan, 2015b).

Several factors have been identified that contribute to overall CI performance in traditional CI candidates. Two factors that are well-documented predictors of post-CI performance include length of deafness of severe-to-profound hearing loss and pre-CI speech recognition scores (Gomma, Rubenstein, Lowder, Tyler, & Gantz, 2003; Rubenstein, Parkinson, Tyler, & Gantz, 1999). Rubenstein et al. (1999) examined the correlation between pre-CI Central Institute for the Deaf (CID) sentence recognition and post-CI consonant-vowel nucleus-consonant (CNC) monosyllabic word performance in a group of post-lingually deafened adults. Subjects were evaluated pre-CI with CID sentences and post-CI with CNC words. The combination of sentence and word measures was used to avoid floor and ceiling effects. Results showed that individuals with better pre-CI sentence scores had increased post-CI word scores. In the same study, association between length of deafness and mean CNC word recognition post-CI was evaluated. Findings revealed individuals with short durations of severe-to-profound hearing loss in the ear to be implanted typically perform better on post-CI speech recognition compared to those with longer durations deafness. For CI recipients with similar lengths of deafness, individuals with better pre-CI sentence recognition had better post-CI monosyllabic word scores. Authors reported length of deafness to be the most important predictor of post-CI performance (Rubenstein et al., 1999).

Similarly, Gomma et al. (2003) examined correlations between duration deafness and pre-CI speech recognition on post-CI performance in 60 post-lingually deafened adults. These

traditional CI recipients had severe-to-profound hearing loss ranging in duration from 1 month to 57 years. Evaluations took place pre-CI using CID sentences, and post-CI at 3 and 6 months using CNC words. Results indicated duration of deafness to be the most stable predictor of post-CI performance. On average, post-CI speech recognition decreased 0.8% with every additional year of severe-to-profound hearing loss. Results further indicated that better pre-CI sentence recognition was directly associated with improved post-CI word recognition. In CI recipients with longer duration deafness and poor sentence recognition, word recognition performance was also lower. Alternatively, CI recipients with better pre-CI sentence recognition exhibited better post-CI word recognition compared to CI recipients with poorer pre-CI sentence recognition.

Plant et al. (2015b) further supported length of severe-to-profound hearing loss in the ear to be implanted as a primary predictor of both unilateral and bilateral post-CI outcomes in 65 CI recipient adults, all who had some degree of pre-CI acoustic hearing in one or both ears. The study examined several variables relation to post-CI speech recognition, including: length of severe-to-profound hearing loss in the implanted ear, age at implantation, contralateral audiometric thresholds and contralateral pure-tone average (PTA) at 500, 1000 and 2000 Hz. Speech recognition was examined pre-CI and out to 12 months post-CI. Unilateral CI recipients with shorter duration severe-to-profound hearing loss in the implanted ear and poorer contralateral ear unaided PTA exhibited significantly better post-CI word scores in quiet than individuals with longer duration deafness and better contralateral PTA. These factors accounted for 34.1% of post-CI word score variance. There was no significant correlation between pre-CI audiometric thresholds in the implanted ear and unilateral post-CI speech recognition. In bilateral CI recipients, significantly higher bilateral post-CI word scores in quiet and SRT in noise were found in individuals with shorter length of deafness, better contralateral audiometric

thresholds and younger age at implantation. These factors accounted for 30.6% of the variance for post-CI bilateral word scores in quiet and 30.9% of the bilateral SRT in noise variance. Overall, shorter length of severe-to-profound hearing loss in the implanted ear significantly correlated with better speech recognition outcomes in both unilateral and bilateral conditionals. Better contralateral audiometric thresholds were found to predict poorer unilateral speech recognition scores in the implanted ear, but better speech recognition scores in the bilateral condition.

In a large study by Holden et al. (2003), post-CI word recognition was examined among 115 post-lingually deafened unilateral traditional CI recipients. Performance was investigated between device activation and two years post-CI using CNC word recognition. CI recipients were divided into 6 outcome groups based on final scores of post-CI speech recognition. The mean CNC two months post-activation was 23.3%, whereas the CNC final score at 2 years post-activation was 61.5%. Data revealed that individuals reached a stable plateau on word recognition performance at 6.3 months post-activation. CI-recipients CNC scores rose 38.3 percentage points at 6.3 months post-CI compared to at two weeks post-CI. Results indicated that pre-CI sentence recognition was a significant predictor of post-CI final CNC scores, with better pre-CI speech recognition scores corresponding to better final CNC word recognition.

As previously mentioned, in 2014 the FDA expanded CI criteria for a new type of CI, the Cochlear Nucleus Hybrid. The Hybrid CI is designed for individuals with normal to moderate hearing loss in the low frequencies, sloping to severe-to-profound hearing loss in the high frequency regions in the ear to be implanted. The external speech processor combines hearing aid and cochlear implant technology by delivering electric and acoustic stimulation. The acoustic

stimulation delivered by the hearing aid component may improve speech understanding and sound localization. (Lenarz et al., 2013; Yawn, Hunter, Sweeney, & Bennett, 2015).

A clinical trial of the Hybrid CI consisted of 50 CI recipients implanted at 10 different sites around the United States. All subjects had low frequency hearing ≤ 60 dB HL at 125 Hz – 500 Hz, and severe hearing loss ≥ 75 dB HL at 2000 Hz and above in the implanted ear. CNC word recognition measured pre-CI ranged between 10% - 60% in the acoustic-only condition. Post-CI speech recognition was assessed at 3, 6 and 12 months. The majority of Hybrid CI users showed improvements in speech recognition within six months of combined acoustic and electric stimulation, with over 75% experiencing equal or improved speech recognition performance. Specifically, subjects exhibited a significant 35.8 percentage point increase in CNC word scores in noise from pre-CI measures. AzBio sentence scores in noise also significantly increased pre- to post – CI, with an average improvement of 32%. Self-assessment measures indicated that speech intelligibility and listening satisfaction increased significantly with the Hybrid CI (Roland, Gants, Waltzman, Parkinson, & The Multicenter Clinical Trial Group, 2015).

Several European investigators studied performance outcomes of combined acoustic and electric stimulation in 66 adult Hybrid CI recipients. Speech recognition, sound quality and quality of life were examined pre- and post-CI out to one year in quiet and noise. All subjects had hearing thresholds ≤ 60 dB HL in low frequencies (below 500 Hz) and severe-to-profound hearing loss in the high frequencies. CNC words were administered in a variety of seven different languages to ensure all evaluations were in individuals' native speech. Mean improvements were observed in speech recognition compared to pre-CI testing, with 65% of participants experiencing speech recognition improvements in quiet and 73% in noise. Additionally, a ≤ 20% benefit in speech recognition was found when using the Hybrid CI's

acoustic feature instead of CI alone. Data from self-assessments provided evidence that mean subjective sound quality and quality of life increased compared to pre-CI (Lenarz et al., 2013).

Predictors of CI performance are important for pre-CI expectation counseling. Advising on time course expected for a recipient to achieve the best CI performance is important to a CI candidate. The rate of improvement for individuals varies notably, as several studies have demonstrated (Holden et al., 2013; Amoodi et al., 2012; Blamely et al., 2013; Friedland, Venick, & Niparko, 2003; Gantz et al., 1988). Reeder and colleagues (2014) completed a longitudinal study on 21 sequentially bilaterally implanted adults with severe-to-profound hearing loss. Length of deafness ranged between less than 1 year to 45 years for the first ear, and from less than 1 year to 55 years for the second ear. Speech recognition testing was administered prior to second ear implantation and after 1, 3, 6, 9 and 12 months of bilateral CI use. Results revealed that within 3 – 6 months of bilateral device use, most post-lingually deafened adults experienced second ear outcomes similar to that of the first ear. CI recipients with longer lengths of deafness in the second implanted ear demonstrated poorer speech recognition performance than individuals with shorter lengths of deafness. These findings imply that length of deafness can be used to predict CI outcomes and provide counseling on time course for best performance.

The studies described above support length of severe-to-profound hearing loss and pre-CI speech recognition scores as primary predictors of post-CI performance. Clinical research has not yet identified how performance will vary for non-traditional CI recipients with more acoustic hearing pre-CI (Gomma et al., 2003; Holden et al., 2013; Hughes, Neff, Simmons, & Moeller, 2014; Plant, van Hoesel, McDermott, Dawson, & Cowan, 2015a; Plant et al., 2015b; Rubenstein et al., 1999). The expanded CI candidacy criterion introduces an additional performance variable to be investigated: CI recipients with more acoustic hearing pre-CI. There is new evidence

indicating these non-traditional CI recipients have been doing well (Amoodi et al., 2012; Hughes et al., 2014; Plant et al., 2015a).

Hughes et al. (2014) examined performance in 37 non-traditional, regular CI recipients with audiometric thresholds $<$ 70 dB SPL at two or more frequencies. The objective of this study was to determine whether non-traditional CI recipients performed better with a CI than with a hearing aid. CI recipients were divided into 3 groups based on pre-CI speech recognition. Speech recognition measures included HINT and AzBio sentences in quiet, as well as CNC words and phonemes in quiet. Data revealed that the majority of CI recipients had improved speech recognition performance post-CI than with a hearing aid. Speech recognition using a CI compared to using a hearing aid at pre- CI evaluations was improved in 28 participants, while five did not exhibit any change in performance. Such improvements in speech recognition in non-traditional CI recipients led the authors to suggest that CI selection criteria should be expanded to include CI candidates with more pre-CI residual hearing. When individuals were broken up into 3 different groups (one with better pre-CI speech recognition scores, one with better pre-CI audiometric thresholds, and one with both) researches found no significant difference in likelihood of success with the CI.

Similarly, Plant et al. (2015a) reported speech recognition findings from a longitudinal study of 19 non-traditional CI recipients. These individuals were considered non-traditional because they had greater speech recognition scores in the ear to be implanted (≥ 46% on monosyllabic phonemes) than guidelines recommended. Pre-CI CNC phoneme scores ranged from 46 to 92%, and 75% of subjects scored ≥ 70 percentage points pre-CI. All CI-recipients were previous bilateral hearing aid users. Clinical performance was assessed pre-CI and 12 months post-CI in the bimodal (CI and hearing aid) aided condition. Subjective questionnaires

were also administered twice for each subject. Improvements were found in aided thresholds and monosyllabic words in quiet and Australian CUNY sentences in noise. Overall, 18 out of 19 individuals improved post-CI from pre-CI. In quiet, mean word scores improved from 44.4% pre-CI to 75.3% 6 months post-CI. In noise, 13 out of 17 participants showed post-CI improvement. Speech recognition was found to improve even when non-traditional CI recipients lost all acoustic hearing post-CI. The bulk of subjects indicated on questionnaires that they believed their CI's helped in situations where they most wanted improvements pre-CI. These data further implied positive outcomes for CI recipients with greater pre-CI speech recognition scores than current guidelines recommend.

The aim of the current study is to examine pre and post-CI speech recognition performance for CI recipients with varying degrees of acoustic pre-CI hearing. A secondary aim is to determine the timeline to reach optimal performance for CI recipients based on degree of acoustic hearing prior to implantation. We hypothesized that CI recipients with greater degrees of acoustic hearing pre-CI would take longer to reach optimal performance. We further hypothesized that the data from this study could serve as a predictor of time course for improvement with a cochlear implant for adults depending on degree of pre-CI hearing.

MATERIALS AND METHODS

Data was reviewed for all CI recipients from electronic medical records from initial evaluation through 6 months post-CI activation. Information was collected from 2/2/2016 – 2/20/2016. No new testing was administered. The study was approved by the Human Research and Protection Office (HRPO # 201511072) at Washington University School of Medicine (WUSM) in St. Louis.

Participants

The study was a retrospective chart review of 203 CI recipients implanted between January 2012 and August 2015. All subjects were seen at WUSM; Department of Otolaryngology; Adult Cochlear Implant and Aural Rehabilitation Program for initial stimulation, programming and rehabilitation. Selection criteria for CI recipients included in the study were as follows: 18 years or older; post-lingually deaf; at least six months of CI experience; English as primary language. In addition, only participants with pre-CI, post-CI testing at 1, 3, and 6 months in words and/or sentences were analyzed. Data from 70 CI recipients were included in the study. The main reasons for exclusion were missing evaluations or varied test conditions.

There were 41 males and 29 females included in the study. Mean age at onset of hearing loss was 33.47 years (SD = 20.13). Length of hearing loss for all subjects ranged from 0.61 to 64.18 years, with a mean length of 29.15 years (SD 17.51). The CI recipients' ages at time of implantation ranged from 20.47 years to 90.13 years, with a mean age of 63.12 (SD = 13.58). Duration of severe-to-profound hearing loss ranged from 0.42 years to 55 years, with a mean of 10.92 years (SD = 13.58). There were 15 individuals with unknown lengths of severe-to-profound hearing loss. Etiologies of hearing loss included: aminoglycoside antibiotics, autoimmune disease, congenital causes, genetic causes, glomus tumor, measles, meduloblastoma, chemotherapy, Menieres disease, nerve damage, noise exposure, otosclerosis, TM perforation, viral infections and unknown causes. At the time of the pre-CI evaluation, all recipients had severe to profound hearing loss in the high frequencies in the ear to be implanted. See Table 1 for details.

Audiometric Thresholds and Speech Recognition Evaluations

Pre-CI audiograms were reviewed from electronic medical records. See Figure 1. CI recipients were divided into three groups based on degree of PTA pre-CI. One group, the mild to moderate group, consisted of 21 CI candidates with PTA ≤ 55 dB HL. A second group, the severe group, consisted of 28 CI candidates with PTA between 71-90 dB HL. The third group, the profound group, consisted of 21 CI candidates with PTA ≥ 91 dB HL. Participants with PTA between 56 – 70 dB HL were excluded from this study due to the small N in this group and the small difference in hearing thresholds between the mild-moderate group and the severe group.

Pre-CI speech recognition scores derived from CI recipient evaluations were examined. Testing was performed both binaurally and in individual ears. All speech materials were administered in the soundfield with recipients seated at 0° azimuth. Aided testing included: soundfield thresholds from 250 – 6000 Hz, consonant-vowel nucleus-consonant (CNC) words in quiet at 60 dB sound pressure level (SPL), AzBio sentences in quiet at 50 and 60 dB SPL, Texas Instruments and Massachusetts Institute of Technology (TIMIT) sentences in quiet at 50 and 60 dB SPL and AzBio sentences at 60 dB SPL with four-talker babble at + (8) dB signal-to-noise ratio (SNR).

Post-CI performance was obtained from evaluations performed at 1 month, 3 months and 6 months. Clinical measures in the unilateral (cochlear implant only) and bimodal (cochlear implant and hearing aid) conditions were recorded. Testing included aided soundfield thresholds from 250 – 6000 Hz, CNC words in quiet at 60 dB SPL, AzBio sentences in quiet at 50 and 60 dB SPL, TIMIT sentences in quiet at 50 and 60 dB SPL and AzBio sentences at 60 dB SPL with

four-talker babble at + (8) dB SNR. Due to incomplete data sets for participants tested in the best-aided condition binaurally and in noise, these evaluations were excluded from analysis.

The main priority was to obtain a complete set of CNC word scores (pre-CI and 1, 3 and 6 months post-CI) for participants to be included in the study. Of 69 participants with complete CNC word scores, sentence scores were evaluated and 34 participants with the same measure at each evaluation point chosen for sentence score analysis. One participant who met selection criteria but did not have consistent CNC scores had complete sentence scores (P51); therefore, this participant was included in the sentence analysis to increase the sample size to 35 participants (70 total).

Due to the variations in performance and clinical management, not all subjects had the same sentence test given at the same input level at each evaluation point. In addition, during this same time interval Washington University was transitioning from TIMIT to AzBio sentences as the primary sentence test. Consequently, fewer participants had consistent sentence scores. Sentence tests were converted from TIMIT to AzBio at certain intervals in order to make sentence tests consistent at each evaluation point for each subject. King and colleagues (2012) found that in a group of 21 CI recipients who were administered TIMIT and AzBio sentences in quiet at 60 dB SPL, subjects scored higher on AzBio sentences. The mean scores for TIMIT sentences ranged from 53 to 89%, and means for AzBio sentences ranged from 69 to 98% at the same testing intervals. (King et al., 2012). Therefore, 16% was added to any TIMIT score at 60 dB SPL for which the subject had AzBio at all other test intervals. This was done for 16 participants.

Implantation

Forty-two and 28 subjects were implanted in the left and right ears, respectively. Twenty-four subjects were implanted with the Advanced Bionics (AB) system. Electrode arrays included the Advantage 90k –mid scala and Hi-Res 90k 1J, paired with Naida Q 70, Harmony and Neptune processors. 41 Subjects were implanted with the Cochlear Nucleus system. Processors included the CP810, CP910 and CP920. Cochlear electrode arrays included the Freedom CI24, CI422 and CI 512 devices. 5 CI recipients received the Med El Concert Medium implant, with Opus 2 and Rondo processors. 61 CI recipients were implanted with their first CI, and 9 received a 2nd CI. Participant device information is shown in Table 2.

Statistical Analysis

Statistical analysis comparing the three hearing loss groups was performed using repeated-measures analysis of variance (ANOVA). AzBio and CNC scores were collected at four evaluation points (pre-CI and 1, 3 and 6 months post-CI). Repeated measures ANOVA were performed to analyze differences in scores for each hearing loss group at each time interval. Results were assessed and corrected for sphericity using Mauchly's test and Huynh-Feldt estimates of sphericity. Post hoc analysis of multiple comparisons was adjusted using Bonferroni corrections. Bonferroni corrections analyzed differences in AzBio sentence scores between the hearing loss groups at each time interval. Pearson's chi-squared tests for independence were used to evaluate month to reach significantly best performance for all hearing loss groups for AzBio sentences and CNC words. Due to too small of a sample size, TIMIT scores were not statistically analyzed. Significance was set at 0.05 for all analysis.

RESULTS

Hearing Loss Groups

One-way ANOVA was performed for CI recipient groups comparing two-frequency PTA at 250 and 500 Hz. All three hearing loss groups were found to significantly differ from each other on their PTA (sig = .00). Mean PTA for the mild-moderate group was 42.14 (SD = 10.23), severe group 80.18 (SD = 5.97) and profound group 104.76 (SD = 8.02). One-way ANOVA was performed between groups on duration of hearing loss, revealing no significant difference between groups on duration of hearing loss (sig = .74). Duration hearing loss for the mild-moderate group was on average 25.90 years (SD = 15.53). The severe group experienced a mean duration hearing loss of 29.33 years (SD = 17.11) and the profound group 31.63 years (SD = 19.93). One-way ANOVA was performed between groups on age at implant, and no significant difference was found between the groups on age at implant (sig = 0.28). There is a tendency for mild-moderate group to be implanted later, but it is not a significant difference. On average, all three groups received a CI at 61.85 years old. Mean age at implant for the mild-moderate group was 66.33 years (SD = 9.61), the severe group 60.61 years (SD = 16.42) and the profound group 61.24 years (SD = 14.43).

Word Recognition

Repeated measures ANOVA was performed on hearing loss groups comparing improvement from CNC word score pre-CI to 6 months post-CI. Tests of within subjects contrasts on CNC word scores at each time interval indicated a significant improvement in CNC scores over time, [$F(2.2, 146) = 193.7$, $p = .000$]. The pattern of change across time points is not significantly different between groups. Mauchly's test of sphericity indicated that the assumption of sphericity had been violated ($p = .000$); therefore degrees of freedom were corrected using

Huynh-Feldt estimates of sphericity. Main effects of time, [$F(2.2, 146) = 193.7$, $p = .000$], and hearing loss group, [$F(2, 66) = .101$, $p = .904$], revealed no significant interaction between time and hearing loss group, [$F(4.4, 146.0) = 0.73$, $p = .589$].

Mean CNC word score performance pre- and post CI is shown in Figure 2. The mild-moderate group, shown in green, had a mean pre-CI CNC score of 12.95% and post-CI score of 62.00%. The severe group's average (shown in blue) pre-CI CNC score was 8.63%, while the post-CI score for this group was 66.22%. The mean pre-CI CNC score for the profound group, shown in red, was 6.94%, with a post-CI average of 62.29%. A significant improvement in word score from pre- to post-CI was found for all hearing loss groups. This is indicated by the asterisk. There was no significant difference between hearing loss groups on word scores at each evaluation point. Overall, all pre-CI scores were low; however, the mild-moderate group had the highest mean word score pre-CI and the lowest mean word score post-CI.

Mean improvements in CNC word score from pre- to post implant evaluation for each of the 3 hearing loss groups are shown in Figure 3. The mild-moderate group (green) exhibited the smallest improvement of 49.05% (SD = 20.63). The severe group (blue) showed the largest mean improvement of 57.59% (SD = 17.66) pre-CI to post-CI, and the profound group (red) improved 55.38% (SD = 25.30). CNC word scores for each of the evaluation points for the three groups iareplotted in Figure 4. The mild-moderate group is shown by the green line, severe group the blue line, and the profound group is shown in red. All hearing loss groups exhibited an improvement in word scores over time. Additionally, hearing loss groups did not differ from each other on CNC word scores at each time interval. Small differences between groups are noted for all evaluations, with the significant notable improvement in post-CI scores.

Figure 5 shows CNC word score percent correct on the y axis for each individual participant for the 3 groups. Hashed marks indicate pre-CI CNC score and solid lines indicate overall highest post-CI score, regardless of time interval. Each group had individuals with low pre-CI performance, with many scoring 0% on words. Post-CI performance shows a large range of variability, with some poor performers (scoring 30%) and some good performers (scoring ≥ 90%). Many participants who had very low pre-CI scores rose to a notable improvement post-CI. Mean pre- and post-CI scores for each group are graphed in the far right column.

All participants exhibited an improvement from pre-CI CNC score by 6 months. Significantly best scores for post-CI CNC word score were determined using a critical difference table (Carney & Schlauch, 2007; Thornton & Raffin, 1980). Sixty-six out of 69 participants exhibited improvements that were considered critically different from pre-CI. While these three participants' (P3, P55, P56) post-CI performance was still higher than their pre-CI performance, it was not considered critically different from their pre-CI score. Hearing loss groups were not found to statistically differ on month to meet significantly best performance. Pearson's chi-square test analyzing groups' evaluation point to reach their significantly best performance on CNC words in quiet revealed no significant difference between groups ($\chi^2(4) = 41.55$, $p = .336$).

Month to reach significantly best performance for each of the groups is pictured in Figure 6, with green indicating best performance by 1 month, blue by 3 months and red for 6 months. The majority of the mild-moderate group (55%) reached their significantly best performance by 3 months, with 45% reaching it by 1 month and 0% by 6 months. The majority of the severe group's participants reached significantly best performance by 1 month (56%), while 32% reached it at 3 months and 11% at 6 months. Of the participants in the profound group, the majority (56%) met significantly best CNC performance by 1 month, 33% by 3 months and 11%

by 6 months. There is an overall trend for participants to reach significantly best performance sooner as hearing loss group PTA becomes worse. Specifically, the majority of the profound group (63%) and severe group (56%) reached significantly best on performance by 1 month, while the majority of the mild-moderate group (55%) reached this at 3 months.

Sentence Recognition

Repeated measures ANOVA was performed on hearing loss groups comparing improvement from AzBio sentence score Pre-CI to 6 months. The sample size for participants completing TIMITs was too small to perform an analysis on; therefore, only AzBio sentence scores were analyzed. Tests of within subjects contrasts revealed a significant improvement in AzBio scores over time, [F(2.1, 68.2) – 231.21, p = .000]. Mauchly's test of sphericity indicated that the assumption of sphericity had been violated (p = .000), therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity. Main effects of time, [F(2.1, 68.2) – 231.21], p = .000, and hearing loss group, [F(2, 32) = 0.24, p = .787], revealed a significant interaction between time and hearing loss group, [F (4.3, 68.2) = 2.68, p = .036]. This pattern of change across time points is significantly different between groups. Analysis of variance showed a significant effect of hearing loss group on improvement over time, [F (4.3, 68.2) = 2.68, p = .036]. Bonferroni adjusted post-hoc comparisons indicated no significant difference in AzBio sentence scores between the hearing loss groups at each time interval.

Mean AzBio and TIMIT sentence performance pre- and post-CI in graphed in Figure 7. On average, the mild-moderate group (shown in green) exhibited a mean pre-CI sentence score of 17.25% (SD = 16.36) and post-CI score of 71.06% (SD = 19.99). The severe group's average pre-CI sentence score was 9.44% (SD = 14.05), while the post-CI score for this group was

73.00% (SD = 24.00). Scores for the severe group are pictured in blue. The mean pre-CI sentence score for profound group was 1.53% (SD = 4.05), and post-CI average 71.60% (SD = 19.89). Because statistical analysis was only performed for AzBio sentences, mean AzBio sentence performance pre-and post-CI is graphed in Figure 8. A significant improvement in AzBio sentence score from pre- to post-CI was found for all hearing loss groups. The asterisk indicates this. There was no significant difference between hearing loss groups on word scores at each evaluation point

Figure 9 shows improvements in AzBio and TIMIT sentence score from pre- to post implant evaluation for each of the 3 hearing loss groups. On average, the mild-moderate group shown in green exhibited a 53.81% (SD = 18.41) improvement on AzBio and TIMIT sentence score in quiet from pre-CI to post-CI. The severe group, shown in blue, showed a mean improvement of 63.56% (SD = 23.90) pre-CI to post-CI. The profound group, portrayed in red, improved on average 70.07% (SD = 21.90).

Sentence scores for each of the evaluation points are plotted in Figure 10 for each of the three hearing loss groups. The mild-moderate group is shown in green, the severe group in blue, and the profound group in red. All hearing loss groups exhibited an improvement in word scores over time. Additionally, hearing loss groups did not significantly differ from each other on word scores at each post-CI time interval. Small differences between groups are noted for all evaluations, with the significant notable improvement in post-CI scores. Variation is observed between hearing loss group in sentence scores at the pre-CI evaluation; however, by the 6 month evaluation all participants are performing similarly.

Figure 11 shows AzBio and TIMIT sentence scores percent correct on the y axis for each individual participant for the 3 groups. Pre-CI CNC scores with a hearing aid are indicated by

hashed marks, and solid bars indicate overall highest post-CI score. Mean pre- and post-CI scores for each group are graphed in the far right column. Each group had individuals with low pre-CI performance, with many scoring 0% on words. Post-CI performance shows a large range of variability, with some poor performers (scoring 30%) and some good performers (scoring ≥ 98%). Many participants who had very low pre-CI scores rose to a notable improvement post-CI.

Post-CI AzBio and TIMIT significantly best performance sentence scores were obtained using a critical difference table (Carney & Schlauch, 2007; Thornton & Raffin, 1980). Improvements considered critically different from pre-CI scores were exhibited in 48 participants, while one participant (P27) did not experience this improvement. P27 did improve overall by 11%. Hearing loss groups were not found to statistically differ on month to reach significantly best performance Pearson's chi-square test analyzing groups' months to meet best performance on AzBio words only revealed no significant difference between groups ($\chi^2(4) = 1.88$, $p = 0.758$).

Month to reach significantly best performance for AzBio and TIMIT sentences was combined for each of the groups and shown in Figure 12. Green indicates best performance by 1 month, blue by 3 months and red for 6 months. No participants from the mild-moderate group reached significantly best performance by 1 month, but 67% reached it by 3 months, and 33% by 6 months. Of the severe group's participants, 20% met significantly best performance by 1 month, 40% at 3 months and 40% at 6 months. The majority of participants in the profound group reached significantly best performance by 1 month (67%), 22% at 3 months and 11% by 6 months. There is a general trend for participants to reach significantly best performance sooner as hearing loss group PTA increases. Specifically, the greater majority of the profound group

(80%) reached significantly best on performance by 1 month, while 60% of the mild-moderate and severe groups reached this at 1 month.

Words and Sentences

Mean month to reach overall highest performance did not differ between AzBio (3.90 months) and TIMIT sentences (3.44 months) collapsed across groups; however, participants reached best performance on CNC words at an average of 2.15 months and on sentences at 3.86 months. The majority of participants met significantly best performance on CNC words at 2.14 months (SD = 1.47). Participants met significantly best performance on AzBio sentences around 1 month, with an average of 1.81 months (SD = 1.26).

There is trend for the mild-moderate and severe group to reach significantly best performance on sentences sooner than CNC words. Mild-moderate group mean best performance for sentences was 2 months (SD=1.44) and 2.1 months (SD = 1.02) for words. Severe group mean best performance was 2 months (SD = 1.46) for sentences and 2.2 months (SD = 1.65) for words. The trend switched for the profound group, whose participants took 1.4 months (SD = 0.83) on average to reach significantly best performance on sentences, and close to 2.05 months (SD = 1.65) for words.

Overall, all three hearing loss groups exhibited the greatest improvements in sentences. The mild-moderate group, shown in green, exhibited a 4.76% greater improvement in sentences than words. The severe group, portrayed in blue, improved 5.96% more on sentences than words. The profound group, graphed in red, exhibited an improvement of 14.69% greater on sentences than words.

The majority of participants exhibited their significantly best improvement in speech recognition scores by 1 month post-CI, regardless of hearing loss group. For CNC words, the majority of the participants (54%) reached this improvement by 1 month. For sentences, the trend is the same. 67% of participants reached their significantly best performance by 1 month. There is an overall trend for more participants to reach best performance sooner on sentences than on words.

DISCUSSION

Results indicate that rate of improvement does not differ from pre- to post-CI for words and sentences, based on degree of hearing loss pre-CI. Performance on all speech recognition measures was better with a CI than with a hearing aid at pre-CI evaluation. 100% of participants experienced an improvement in pre-CI word and sentence scores by 6 months post-CI. Of these, 96% experienced a word score improvement considered critically different from their pre-CI evaluation and 92% on sentences. For CNC words, three participants (P3, P55, P56) did not meet such improvements; however, their post-CI performance was still higher than their pre-CI performance. P3 did not have a complete set of sentence scores to analyze, but P55 and P56 improved significantly on sentences by 1 month. For sentences, one participant (P27) did not experience an improvement post-CI that was considered critically different from pre-CI. This participant showed an overall improvement in sentence scores pre- to post-CI of 11%. Additionally, this individual met a critically different improvement from pre-CI CNC word score by 3 months.

Data in this study agrees with findings by Hughes et al. (2014) study on non-traditional candidates with pre-CI hearing thresholds similar to our mild-moderate group. Researchers found

that 73% of participants performed better using a CI than hearing aids. In addition, these researchers found that when individuals were broken up into 3 different groups (one with better pre-CI speech recognition scores, one with better pre-CI audiometric thresholds, and one with both) no significant difference in likelihood of success with the CI was found. This data is similar to our study, in which we found no significant difference in likelihood of success with the CI when our CI recipients were broken up into three different groups based on degree of hearing loss. These data provide a clinical implication that CI candidates with greater amounts of pre-CI hearing should continue to be considered CI candidates and benefit from CI.

Hearing loss groups were found to significantly differ from each other on their two-frequency PTA, but not on their word or sentence score. We observed that participants with varying degrees of hearing loss in the low-frequencies pre-CI did not differ in overall speech recognition post-CI. This finding confirms research by Plant et al. (2015b), who also found no significant correlation between pre-CI audiometric thresholds in the implanted ear and unilateral post-CI speech recognition performance. These researchers did find that in subjects with better pre-CI hearing in the contralateral ear, speech recognition scores were poorer than in subjects with worse pre-CI hearing. In our study, all participants reached similar post-CI improvement in speech recognition, regardless of pre-CI hearing level. A trend was found that the mild-moderate group did not experience as much of an improvement as the profound group, but that may be because that their pre-CI scores were higher.

Research by Lenarz et al. (2013) on hybrid CI recipients with hearing thresholds similar to our mild-moderate group, found that 65% of participants exhibited improvements in word recognition in quiet in the unilateral condition by 1-year post-CI. A cohort of word tests were administered in seven different languages to ensure all participants were tested in their native

language. This research is similar to our findings in that the majority of participants experienced improvements in sentence recognition. Our research supports an even greater benefit with the CI than with hearing aids. The majority of our participants (96%) experienced improvements of ≥ 20 percentage points on CNC words, compared to participants in Lenarz et al.'s 2013 study. Additionally, 98% of our participants met this improvement of ≥ 20 percentage points on sentences. The mild-moderate group showed similar improvements as the total, with 95% improving ≥ 20 percentage points on words and 100% on sentences. While findings of Lenarz et al. (2013) indicate an improvement in speech recognition measures by 1 year post-CI, our findings demonstrate larger improvements may be met even sooner. Specifically, the majority of severe and profound CI recipients exhibited significantly best improvements within 1 month, and mild-moderate CI candidates exhibited significantly best improvement within 1 - 3 months post-CI.

Improvement on words and sentences was the smallest for the mild-moderate group. This group had the highest pre-CI scores and lowest post-CI scores for all speech recognition measures. While this group showed the least amount of improvement, this improvement is still beneficial. By the 6 month evaluation the mild-moderate groups post implant mean scores were very similar to other groups. This differs from previous research on traditional CI recipients. Gomma et al. (2003) and Rubenstein et al. (1991) both found that participants with better pre-CI sentence recognition exhibited better post-CI word recognition compared to recipients with poorer pre-CI sentence recognition.

Overall, the mild-moderate group exhibited a 49.05% (SD = 20.64) increase in CNC word scores in quiet by 6 months post-CI. The severe group and profound groups reached improvements of 57.59% (SD = 17.86) and 55.80% (SD = 22.30), respectively. Best word

performance score was achieved by 94% of participants by the 3 month evaluation, with the improvement at this evaluation averaging 58.33 percentage points. The current study showed earlier and better performance on word scores than previous research suggests. Plant et al. (2015a) found that non-traditional CI recipient monosyllabic word scores in quiet improved an average on 30.9 percentage points by 6 months post-CI in the bimodal (CI and hearing aid) condition. Our results also supported earlier and better performance on words than previous research suggested for hybrid candidates. Lenarz et al. (2013) found that hybrid CI recipients had a ≥ 20% improvement in word scores by one year. Similarly, Roland et al. (2015) found that hybrid CI recipients had a mean CNC word score increase of 35.8% by 6 months post-CI. The larger improvement shown by our study may be due to the fact that CNC words were examined in quiet and the Roland study presented CNC words in noise, as words in noise are known to be harder than words in quiet.

While not statistically significant, we observed a clinical trend for participants with poorer pre-CI hearing to reach best performance sooner compared to participants with better hearing pre-CI. The majority of the mild-moderate group (55%) met best performance on CNC words that was considered clinically different from pre-CI by 3 months. Alternatively, the majority of the severe (56%) and profound (63%) groups met best performance at 1 month. The trend is the same for sentences. While 60% of the mild-moderate and severe groups reached best performance by 1 month, 80% of the profound group met this by 1 month. Additionally, all members of the profound group met this performance before 6 months. Overall, we found that significantly best performance on sentences is reached slightly sooner than words. This indicates that best performance has been achieved sooner than a study by Holden et al. (2013), who found that individuals reached a stable plateau on word recognition performance at 6.3 months post-CI,

with an average increase in scores of 38.3 percentage points by this time interval. Our study found a 50.17 percentage point increase in stable word scores by 6 months post-CI, with the average month to reach significantly best performance being 2.14 months. 100% of our participants reached an improvement in CNC scores by 6 months, with 96% reaching an improvement considered critically different from pre-CI. Even though most participants reached significantly best performance on word performance by 6 months, the majority of all participants (55%) reached it by 1 month. Similarly, 67% of participants reached significantly best performance on sentences by 1 month as well, regardless of hearing loss group. This data could be used in expectation counseling for month to reach best performance post-CI based on degree of pre-CI hearing loss.

CONCLUSIONS

Overall, performance on all speech recognition measures was better with a CI than with a hearing aid for all groups. No significant correlation was found between hearing loss group and unilateral post-CI speech recognition performance. The mild-moderate group exhibited the smallest improvements on words and sentence, while the severe and profound groups exhibited the greatest improvements. Each group had similar post-CI word and sentence scores, but varied slightly on pre-CI performance. Mild-moderate group should continue to be considered for a CI and our research supported implanting candidates with lesser degrees of hearing loss.

Significantly best speech recognition performance was reached by 6 months for 92% of participants on sentences and 96% on words. Best performance was achieved on average at 2 months for words and 1 month for sentences for all groups.

Degree of pre-CI hearing loss may predict time course for improvement out to 6 months post-CI. There is a clinical trend for participants with poorer pre-CI low frequency hearing to reach best performance sooner. The mild-moderate CI recipients in this study took longer to meet best speech recognition performance, while severe and profound CI recipients reached it sooner. The improvements in words and sentences observed in this study agree with previous research on non-traditional and hybrid CI candidates.

FUTURE RESEARCH

Possible reasons for the mild-moderate group not to reach the greatest rate of improvement include that all participants were tested in the CI only condition. As noted in the audiograms in Figure 2, hearing loss was the similar in the implanted and contralateral ear. Because the bimodal condition was not consistently measured, it was not included in analysis for this study; however, scores for this condition generally increased as well. This is a possible reason the mild-moderate group is not improving as much as the severe and profound groups overall. Future research should be done to include the bimodal condition to see if wearing a hearing aid on the contralateral ear provides greater improvements for the mild-moderate group than the severe and profound groups. Testing in noise should also be considered, to ensure improvements remain the same in noise for all hearing loss groups. Finally, more research should be examined on CI recipients who are hybrid candidates.

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Table 1. Demographic Information

Demographic and Audiologic Information								
Hearing Loss Group	Participant	Age at Surgery	Gender	Age at Onset HL	Etiology	Pre-CI PTA 250 + 500 Hz	Length of HL	Length of severe-profound HL
Mild-Moderate								
	1	45.43	M	34.92	Unknown	22.50	10.51	10.00
	2	68.37	M	36.25	Noise Exposure	25.00	32.12	0.50
	3	68.57	F	28.81	Genetic	30.00	39.75	2.00
	4	73.06	M	46.88	Unknown	30.00	26.18	8.00
	5	58.42	F	49.52	Nerve Damage	32.50	8.90	1.00
	6	56.19	M	40.34	Noise Exposure	35.00	15.85	1.00
	7	60.33	F	49.52	Unknown	35.00	10.81	4.00
	8	53.80	M	36.42	Unknown	40.00	17.38	Unknown
	9	68.24	M	53.87	Unknown	40.00	14.37	3.00
	10	73.64	M	72.90	Medication	42.50	0.74	0.42
	11	54.56	M	36.42	Unknown	42.50	18.14	Unknown
	12	67.64	M	20.07	Unknown	45.00	47.57	11.00
	13	64.31	F	36.85	Measles	47.50	27.45	8.00
	14	78.84	F	58.99	Unknown	47.50	19.85	2.00
	15	70.44	M	31.86	Noise Exposure	47.50	38.58	6.00
	16	65.48	M	21.02	Noise Exposure	52.50	44.46	Unknown
	17	75.45	M	32.84	Unknown	52.50	42.61	Unknown
	18	59.14	M	37.69	Genetic	52.50	21.45	15.00
	19	79.42	M	26.21	Noise Exposure	55.00	54.22	44.00
	20	84.08	F	75.79	Unknown	55.00	8.30	Unknown
	21	67.58	M	22.93	Noise Exposure	55.00	44.65	21.00
Severe								
	22	54.73	M	Unknown	Unknown	72.50	Unknown	Unknown
	23	48.27	F	47.56	Unknown	72.50	0.71	0.5
	24	90.13	F	79.68	Unknown	72.50	10.45	0.5
	25	67.03	M	50.50	Unknown	72.50	16.53	0.5
	26	44.57	F	0.00	Unknown	75.00	44.57	Unknown
	27	84.52	M	43.03	Unknown	75.00	27.48	0.5
	28	70.78	M	7.24	Unknown	75.00	63.54	20
	29	56.64	M	30.19	Unknown	75.00	26.44	26
	30	71.96	F	24.02	Unknown	75.00	47.94	Unknown
	31	59.92	F	12.18	Autoimmune Disease	77.50	47.74	Unknown
	32	76.05	M	48.75	Virus	77.50	27.30	Unknown
	33	51.03	F	0.68	Aminoglycoside	77.50	50.35	Unknown
	34	75.89	M	25.44	Genetic; Noise Exposure	77.50	50.45	22
	35	27.96	M	11.62	Medulloblastoma; Chemotheraphy	77.50	16.34	1
	36	74.06	M	49.99	Menieres	80.00	24.07	12
	37	55.34	M	40.10	Unknown	80.00	15.24	3.00
	38	54.99	M	24.58	Noise Exposure	80.00	30.41	5
	39	63.15	F	41.09	Unknown	80.00	22.05	0.5
	40	60.28	M	6.86	Unknown	82.50	53.42	40
	41	40.72	M	4.98	Unknown	85.00	35.74	10
	42	77.78	F	57.40	Unknown	85.00	20.38	10
	43	20.47	M	2.66	Unknown	87.50	17.81	0.5
	44	53.50	F	0	Meningitis	87.50	53.50	10
	45	66.45	F	43.85	Unknown	87.50	22.59	Unknown
	46	45.59	M	9.74	Genetic	87.50	35.85	34
	47	83.26	M	60.83	Unknown	90.00	22.43	10.00
	48	53.88	M	53.24	Virus	90.00	0.61	0.5
	49	68.20	F	60.12	Unknown	90.00	8.06	0.5
Profound								
	50	40.57	F	3.05	Unknown	92.50	37.52	Unknown
	51	83.30	M	23.81	Noise Exposure	92.50	59.49	9
	52	67.69	M	18.54	Unknown	92.50	49.15	9
	53	57.59	F	1.61	Congenital	95.00	55.98	55
	54	33.89	F	32.94	Unknown	95.00	0.95	0.5
	55	40.14	F	5.17	Unknown	100.0	34.97	6
	56	85.25	M	21.07	TM Perforation	100.0	64.18	5
	57	64.24	F	10.02	Otosclerosis; Stapedectomy	100.0	54.22	48.00
	58	83.82	F	39.36	Menieres	102.5	44.45	44
	59	61.66	F	37.30	Unknown	102.5	24.36	9
	60	61.88	M	14.48	Otosclerosis	105.0	47.40	Unknown
	61	65.43	M	45.16	Unknown	110.0	20.27	2
	62	66.02	M	65.34	Unknown	112.5	0.68	2
	63	71.36	M	66.03	Unknown	112.5	5.33	5
	64	59.96	F	37.30	Unknown	112.5	24.36	9.00
	65	65.03	M	20.94	Noise Exposure	112.5	44.09	Unknown
	66	59.96	F	46.11	Glomus Tumor	112.5	2.48	0.50
	67	70.55	F	53.93	Unknown	112.5	16.62	16
	68	34.53	M	3.24	Unknown	112.5	31.29	2
	69	40.72	F	22.18	Menieres	112.5	18.53	7
	70	72.35	F	44.50	Menieres	112.5	27.85	17
	Mean	**62.76**		**33.29**		**76.92**	**29.26**	**10.74**
	STDEV	**14.37**		**20.48**		**25.25**	**17.42**	**13.65**
	N	**70.00**		**70.00**		**70.00**	**70.00**	**55.00**

Table 2. Cochlear Implant Information

Device Information				
Hearing Loss Group	Participant	Ear	Device	Processor
Mild-Moderate				
	1	L	Cochlear CI422	CP920
	2	L	Cochlear Freedom CI24	CP810
	3	R	Cochlear Freedom CI24	CP810
	4	L	Med El Concert Medium	Opus 2
	5	R	Cochlear Freedom CI24	CP810
	6	L	Cochlear Freedom CI24	CP810
	7	L	Cochlear Freedom CI24	CP920
	8	L	AB Advantage 90k-mid scala	Naida Q70
	9	L	Cochlear CI422	CP920
	10	R	Cochlear Freedom CI24	CP810
	11	R	AB Advantage 90k-mid scala	Naida Q70
	12	R	AB Advantage 90k-mid scala	Naida Q70
	13	L	Cochlear Freedom CI24	CP810
	14	L	Med El Concert Medium	Opus 2
	15	L	AB Advantage 90k-mid scala	Naida Q70
	16	L	AB Hi-Res 90k 1J	Harmony
	17	R	Med El Concert Medium	Rondo
	18	L	Cochlear Freedom CI24	CP920
	19	R	Cochlear Freedom CI24	CP810
	20	R	Cochlear Freedom CI24	CP920
	21	L	AB Advantage 90k-mid scala	Naida Q70
Severe				
	22	L	Cochlear Freedom CI24	CP810
	23	L	AB Advantage 90k-mid scala	Naida Q70
	24	L	Cochlear Freedom CI24	CP920
	25	R	Cochlear Freedom CI24	CP910
	26	R	Cochlear Freedom CI24	CP810
	27	L	Cochlear Freedom Ci 512	CP810
	28	L	Cochlear Freedom CI24	CP810
	29	L	AB Advantage 90k-mid scala	Naida Q70
	30	L	AB Advantage 90k-mid scala	Naida Q70
	31	L	Cochlear Freedom CI24	CP810
	32	L	AB Hi-Res 90k 1J	Harmony
	33	R	AB Hi-Res 90k 1J	Harmony
	34	L	Cochlear Freedom CI24	CP810
	35	L	AB Advantage 90k-mid scala	Naida
	36	L	Med El Concert Medium	Opus 2
	37	L	AB Advantage 90k-mid scala	Naida Q70
	38	R	Cochlear Freedom CI24	CP910
	39	R	Cochlear Freedom CI24	CP920
	40	R	AB Advantage 90k-mid scala	Naida Q70
	41	R	Cochlear Freedom CI24	CP810
	42	R	AB Advantage 90k-mid scala	Naida Q70
	43	L	AB Hi-Res 90k 1J	Harmony
	44	L	Cochlear Freedom CI24	CP910
	45	R	Cochlear Freedom CI24	CP910
	46	L	AB Advantage 90k-mid scala	Naida Q70
	47	L	Cochlear Freedom CI24	CP810
	48	R	Cochlear Freedom CI24	CP920
	49	L	Cochlear Freedom CI24	CP910
Profound				
	50	L	Cochlear Freedom CI24	CP810
	51	R	Med El Concert Medium	Opus 2
	52	L	Cochlear Freedom CI24	CP920
	53	L	Cochlear Freedom CI24	CP810
	54	R	AB Advantage 90k-mid scala	Naida Q70
	55	R	AB Advantage 90k-mid scala	Naida Q70
	56	L	AB Advantage 90k-mid scala	Naida Q70
	57	R	Cochlear Freedom CI24	CP910
	58	R	Cochlear Freedom CI24	CP810
	59	L	AB Advantage 90k-mid scala	Naida Q70
	60	R	Cochlear Freedom CI24	CP810
	61	L	Cochlear Freedom CI24	CP810
	62	L	Cochlear Freedom CI24	CP810
	63	R	AB Hi-Res 90k 1J	Neptune
	64	R	AB Advantage 90k-mid scala	Naida Q70
	65	L	Cochlear Freedom CI24	CP810
	66	R	AB Advantage 90k-mid scala	Naida Q70
	67	L	Cochlear Freedom CI24	CP920
	68	L	Cochlear Freedom CI24	CP910
	69	L	Cochlear Freedom CI24	CP910
	70	R	Cochlear Freedom CI24	CP920

Figure 1. Audiograms

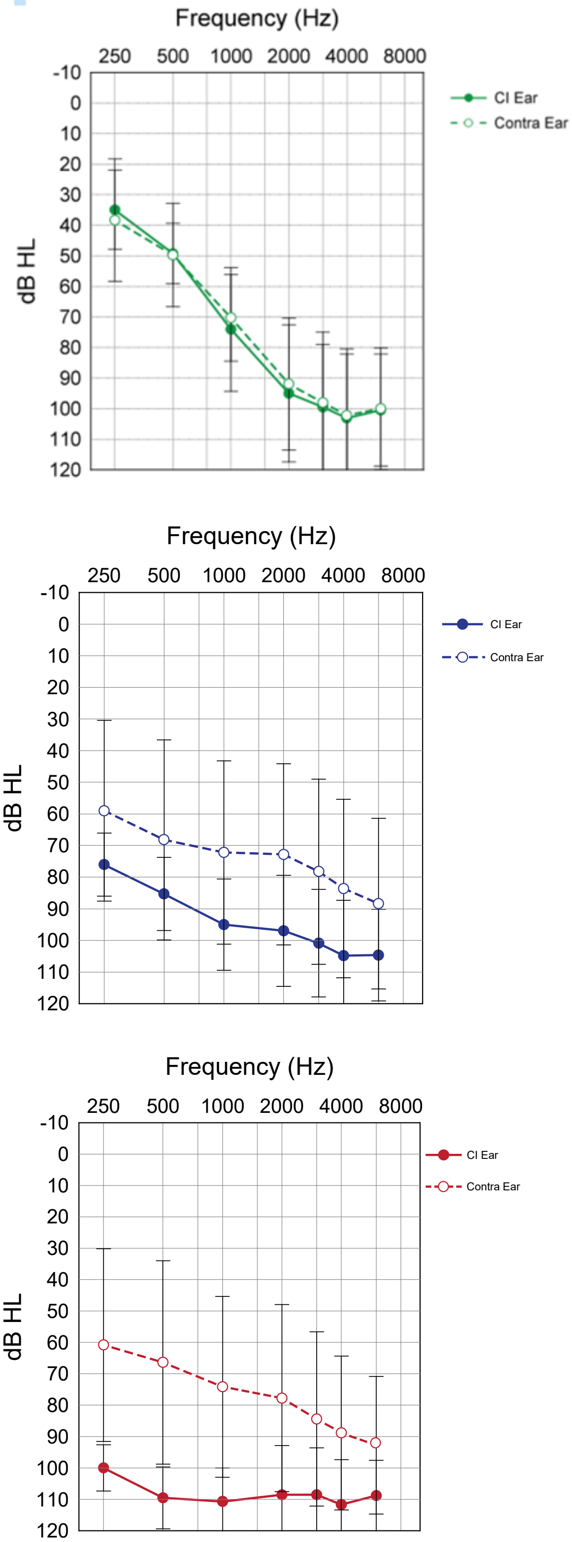

Figure 2. Mean CNC Word Pre-CI to Highest Score Post-CI

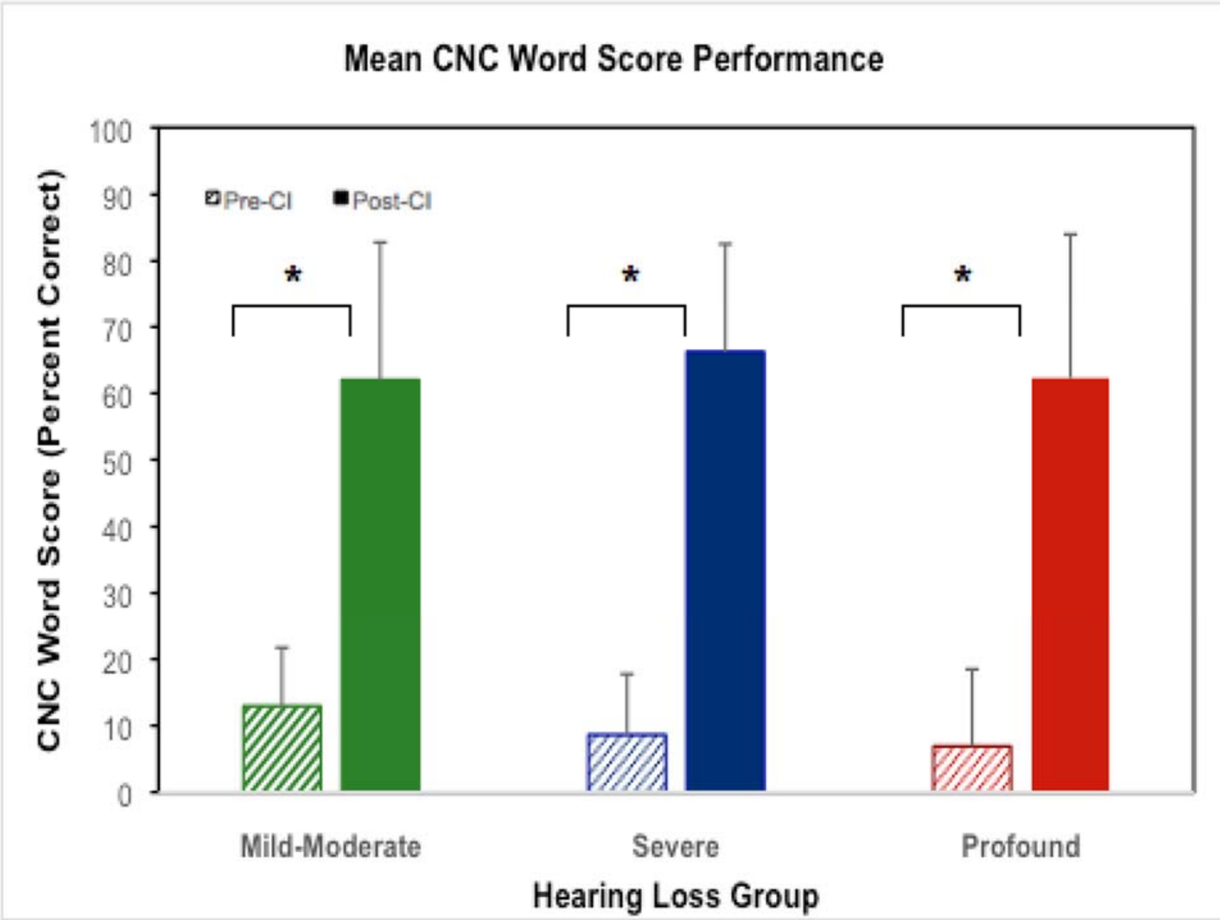

Figure 3. Mean CNC Word Score Improvement

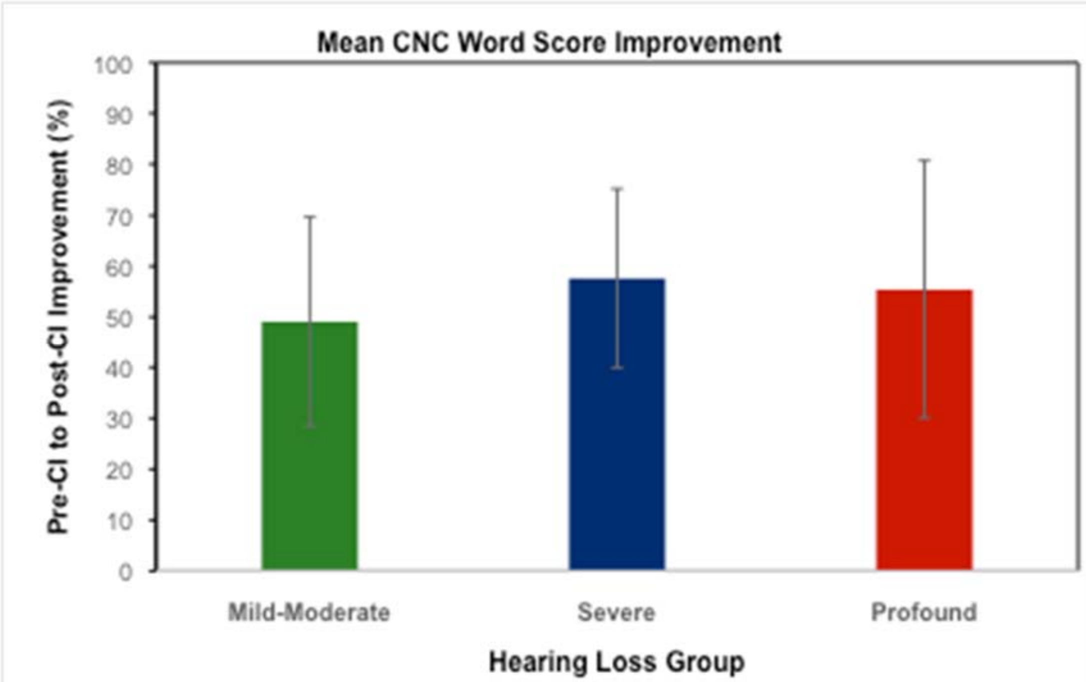

Figure 4. CNC Word Score

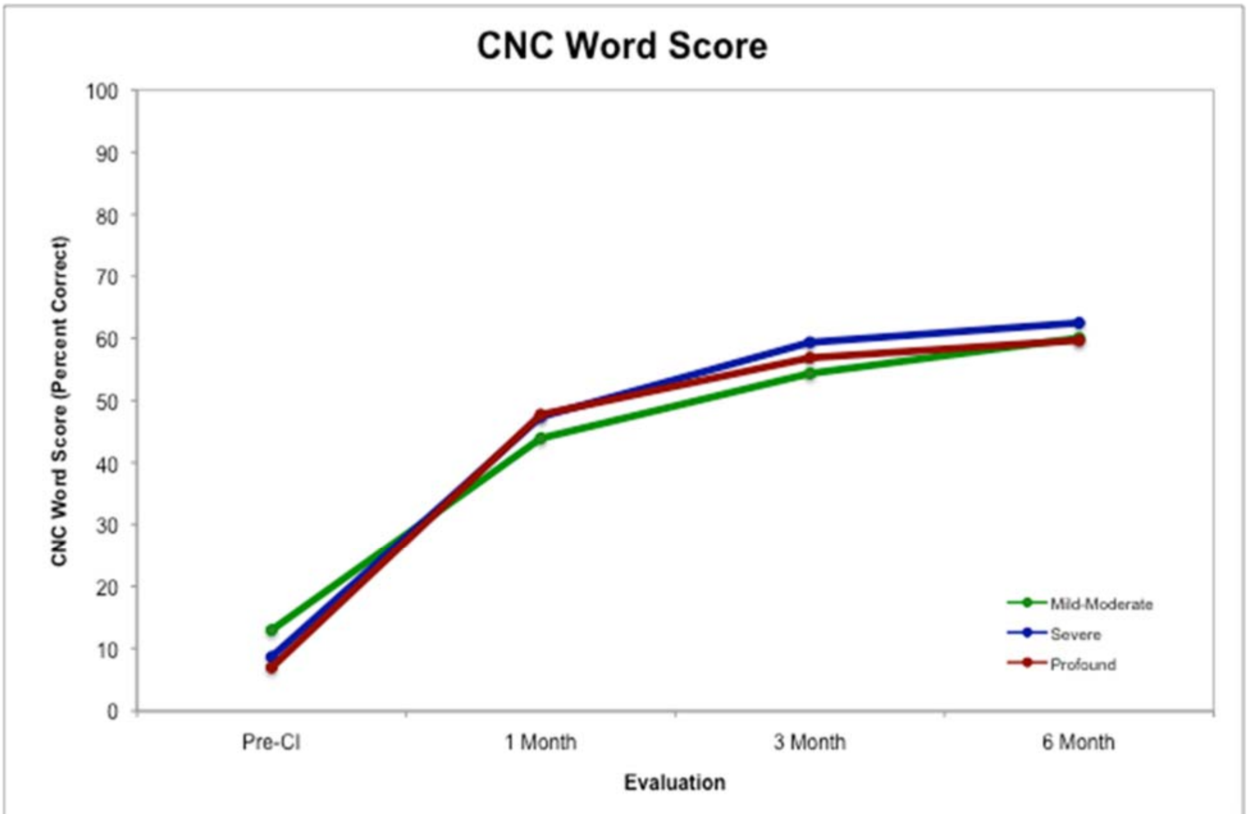

Figure 5. Participants CNC Word Score Pre-CI to Highest Post-CI

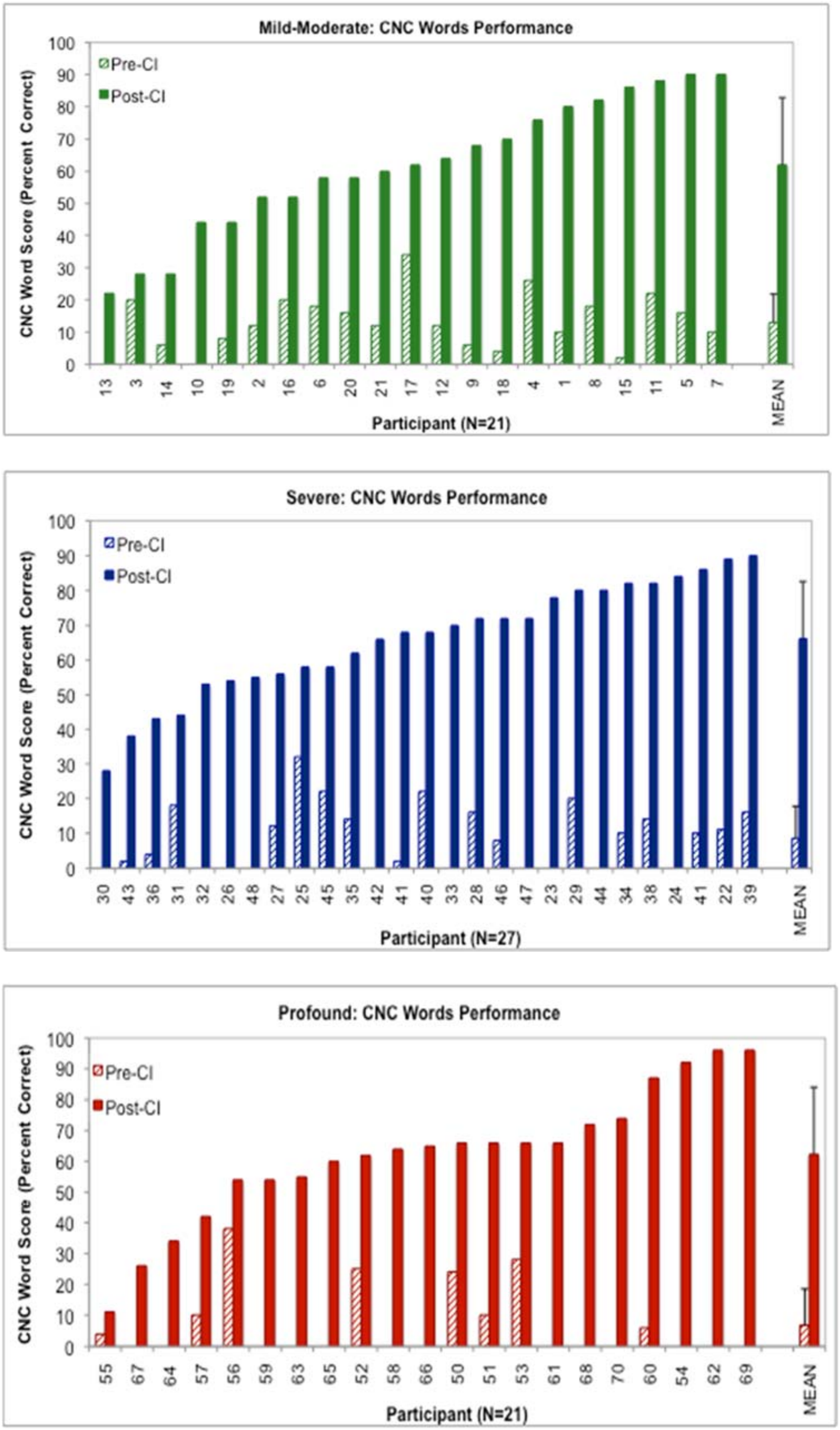

Figure 6. Month to Meet Significantly Best Performance on CNC Words

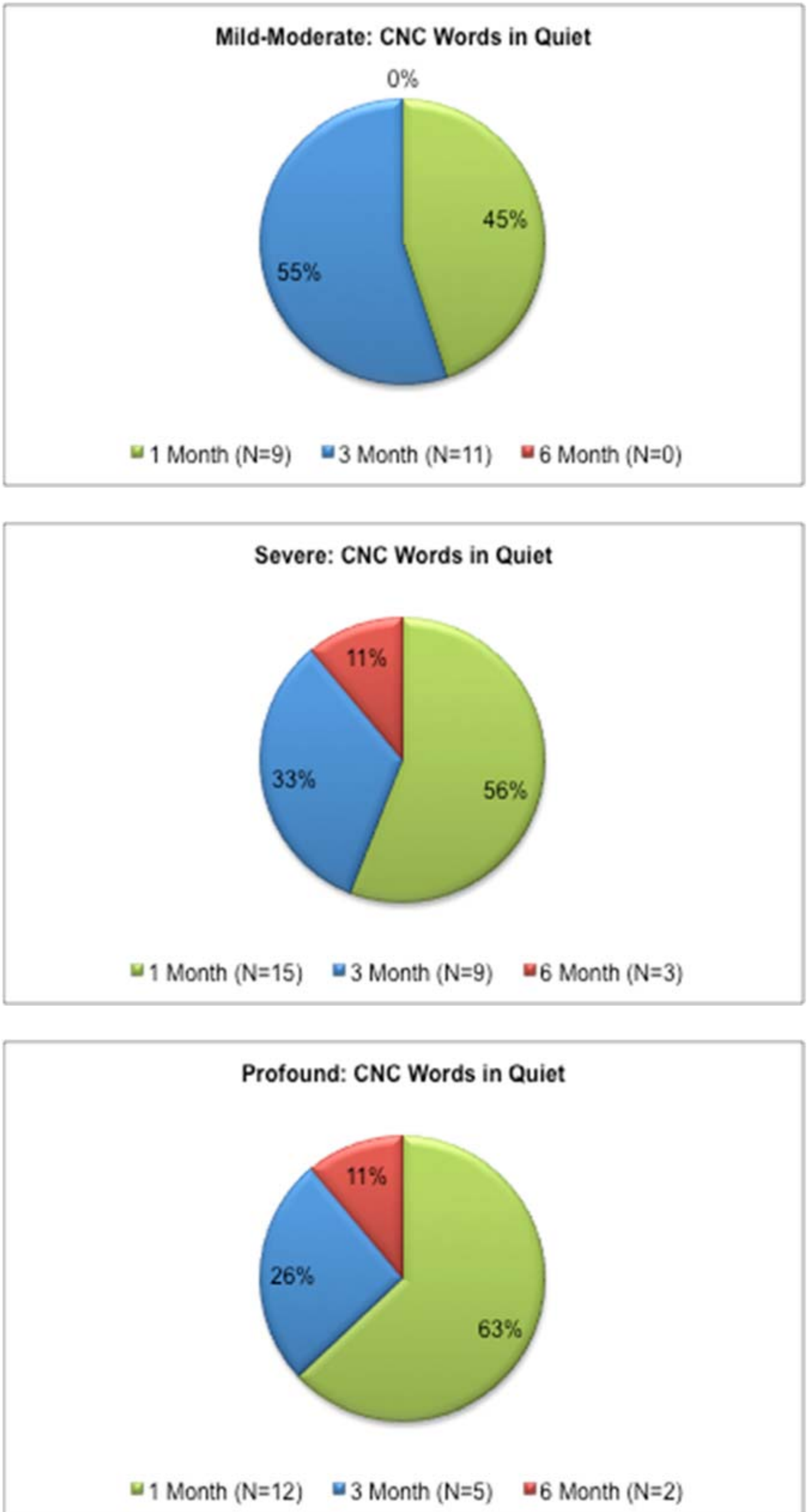

Figure 7. Mean Sentence Score

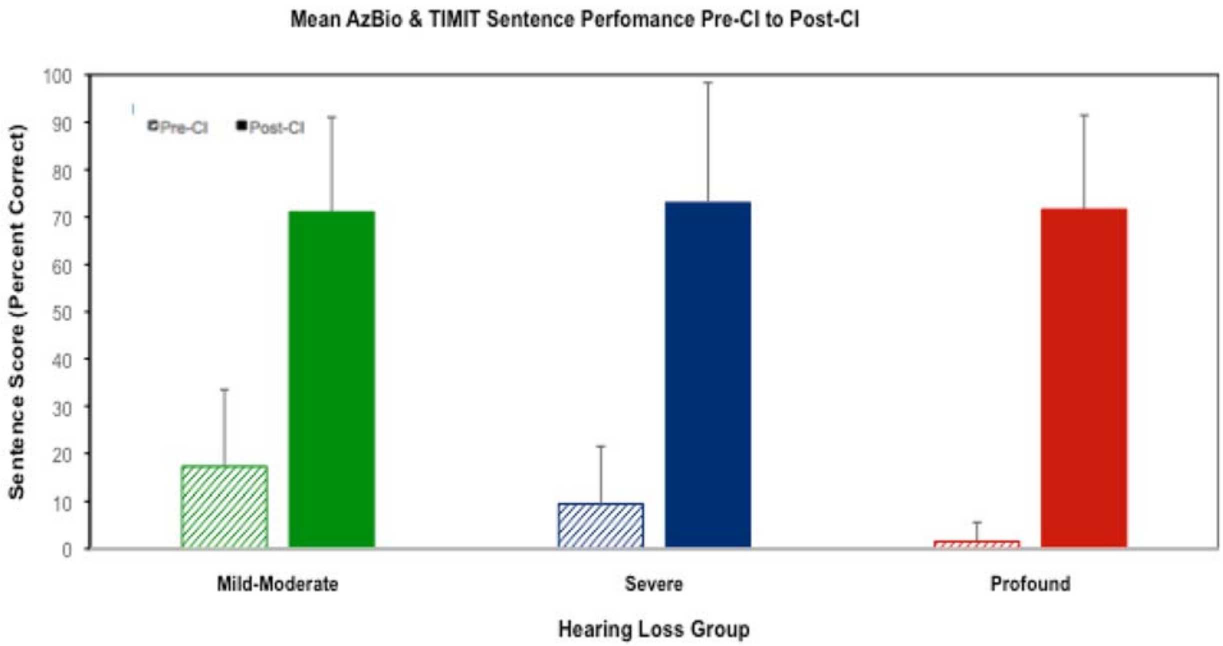

Figure 8. Mean AzBio Sentence Score

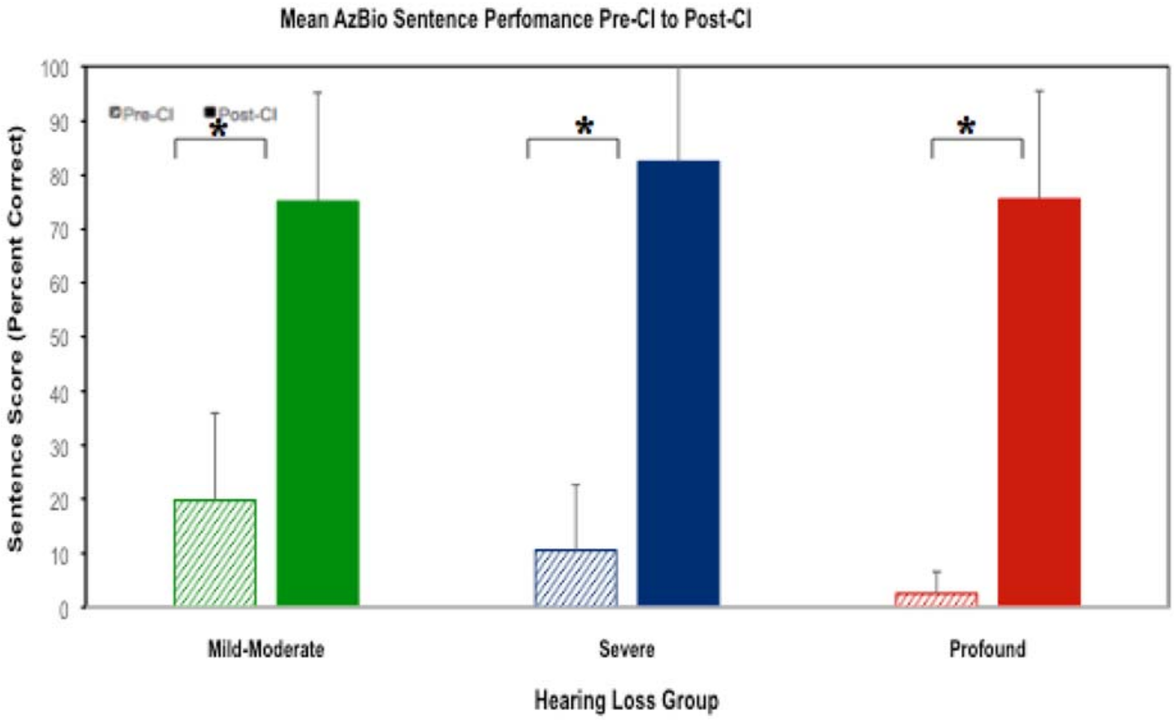

Figure 9. Mean Sentence Score Improvement

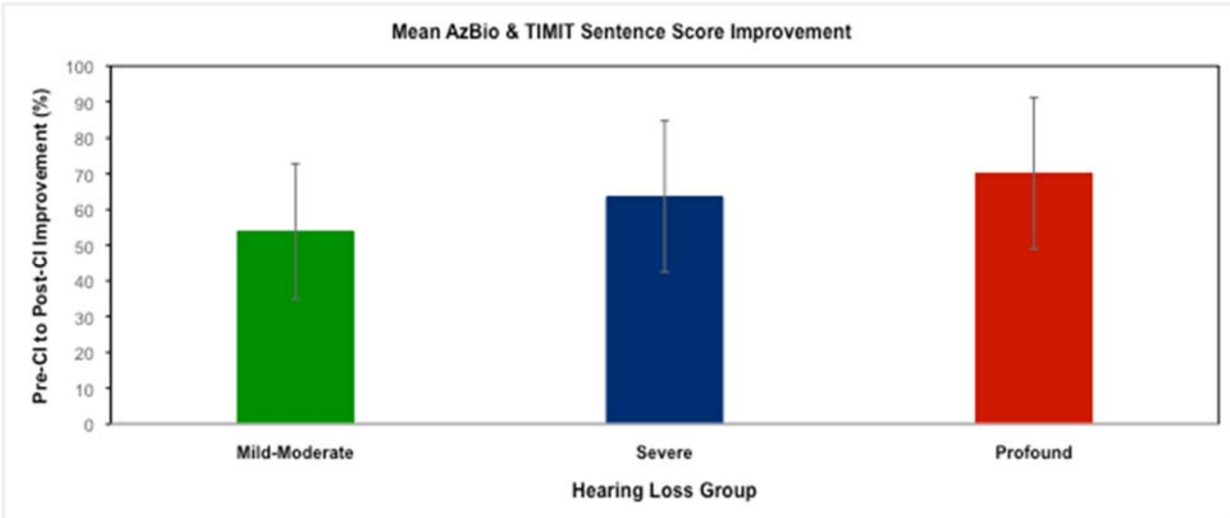

Figure 10. Sentence Score

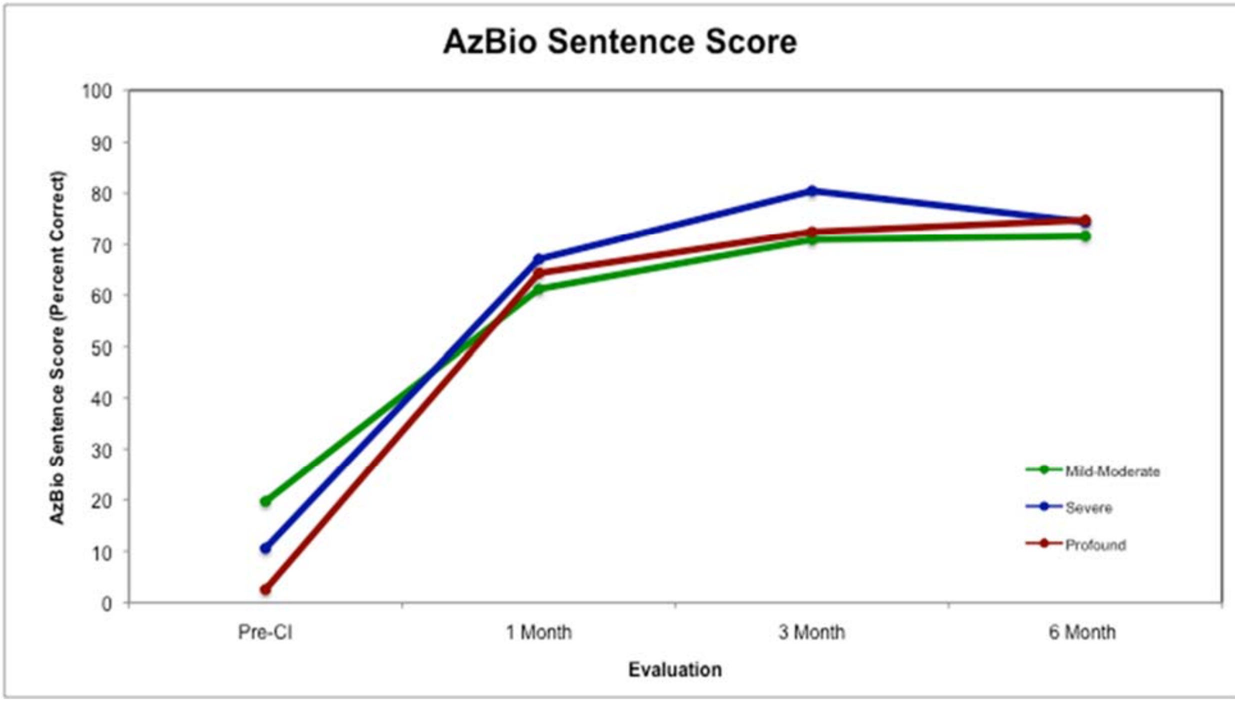

Figure 11. Participants Sentence Score Pre-CI to Highest Post-CI

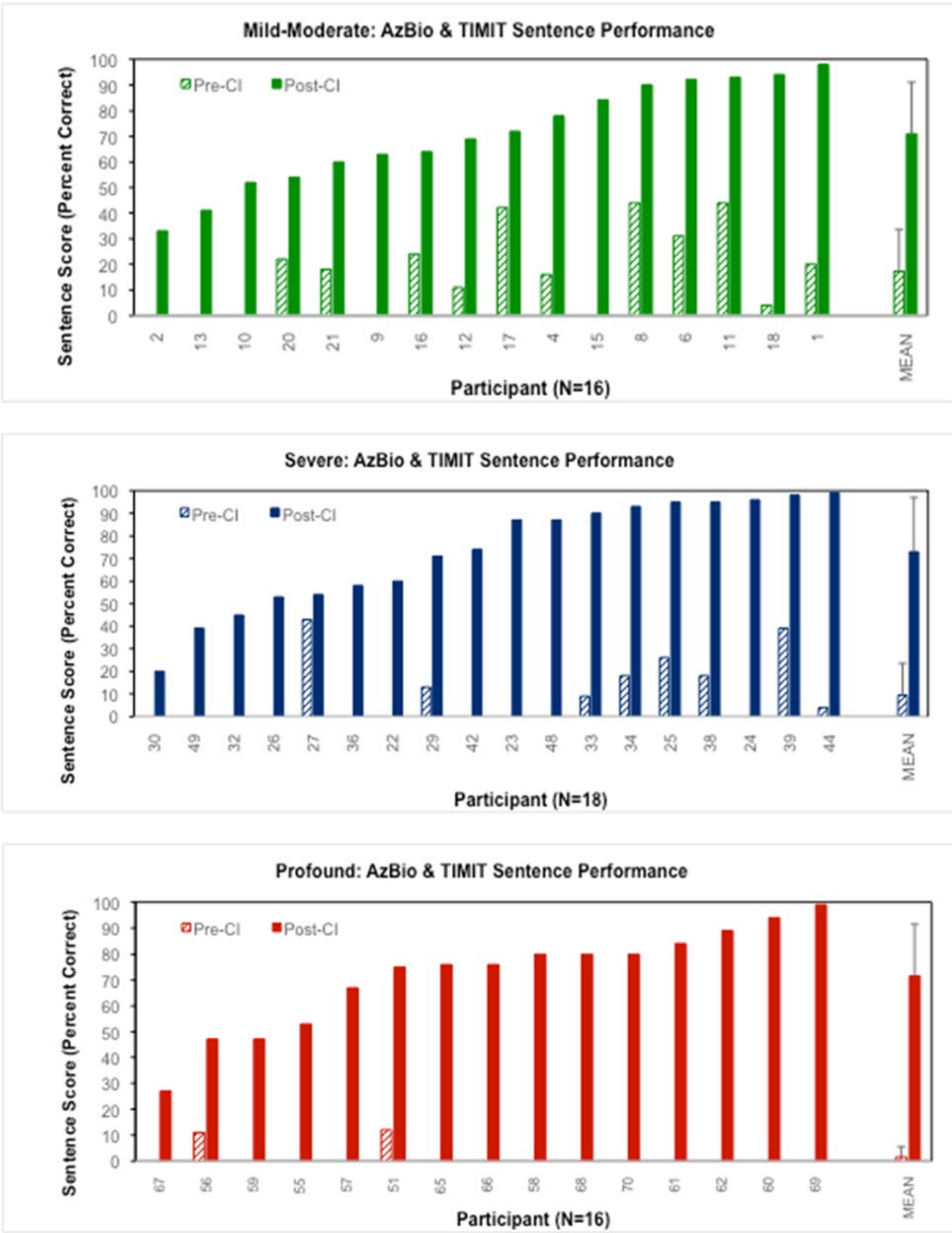

Figure 12. Month to Meet Significantly Best Performance on Sentences