Speech perception scores in cochlear implant recipients: An analysis of ceiling effects in the CUNY sentence test (Quiet) in post-lingually deafened cochlear implant recipients.

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Abbreviations:

CUNY: City University of New York

AzBio: Arizona Biomedical University

CNC: Consonant- Nucleus- Consonant

CI: Cochlear Implant

HINT: Hearing in Noise Test

CID: Central Institute of Deaf

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ABSTRACT

Objectives: To evaluate the clinical utility of the CUNY sentence test in a cohort of post-lingually deafened CI recipients over time.

Methods: 117 post-lingually deafened, Australian English speaking CI recipients aged between 23-98 years (M = 66 years; SD = 15.09) were recruited. CUNY sentence test scores in quiet were collated and analysed at two cut-offs, 95% and 100%, as ceiling scores.

Results: CUNY sentence scores ranged from 4-100% (M = 86.75; SD = 20.65), with 38.8% of participants scoring 95% and 16.5% of participants reaching the 100% scores. The percentage of participants reaching the 95% and 100% ceiling scores increased over time (six and 12 months post-implantation).

The distribution of all post-operative CUNY test scores skewed to the right with 82% of test scores reaching above 90%.

Discussion: This study demonstrates that the CUNY test cannot be used as a valid tool to measure the speech perception skills of post-lingually deafened CI recipients over time. This may be overcome by using adaptive test protocols or linguistically, cognitively or contextually demanding test materials.

Conclusion: The high percentage of CI recipients achieving ceiling scores for the CUNY sentence test in quiet at three months post-implantation, questions the validity of using CUNY in CI assessment test battery and limits its application for use in longitudinal studies evaluating CI outcomes. Further studies are required to examine different methods to overcome this problem.

Keywords: Cochlear implant, Ceiling effect, CUNY sentence test, Speech perception, Long-term outcome, Candidacy.

Introduction

Since the introduction of cochlear implants (CI) in late 1970s, significant improvements have been reported in speech coding and signal processing strategies. This, in turn, has resulted in improved speech perception skills of the recipients (Fabry et al., 2009, Gifford et al., 2008, Lenarz et al., 2012, Ruffin et al., 2007, Gifford et al., 2010). In clinical settings, speech perception outcomes are used to identify the potential candidates for CI surgery and also to evaluate the progress of the CI recipient post implantation (Gifford et al., 2008, Alkaf and Firszt, 2007, Gifford et al., 2010, Dowell et al., 2004, Blamey et al., 1992). Therefore, it is essential to utilise a suitable speech perception test for this purpose.

An ideal speech perception test should be reliable, highly sensitive to differences between test conditions, and correlate well with speech perception abilities in the real world (Mackersie, 2002). Today's post-lingually deafened adult implant recipients, however, demonstrate high levels of speech perception scores-in-quiet with current sentence tests such as Hearing in Noise (HINT) sentence test in the first few months post implantation (Gifford et al., 2008, Gifford et al., 2010, Fabry et al., 2009, Lenarz et al., 2012, Helms et al., 2004). Gifford et al. (2008) reported that 71% of cochlear-implanted adults scored above 85% on a common test of sentence perception in quiet, of whom 28% reached the maximum possible score. This does not provide a realistic view of patients' improvement over time and raises the issue of the ceiling effect.

Studies that used sentence tests to measure the speech perception outcomes of the CI recipients have reported ceiling scores to be a challenge. Firstly, when two different conditions, such as two speech coding strategies or two different programs are compared, reaching the ceiling scores leaves no room for such comparisons (Koch et al., 2004, Spahr and Dorman, 2005, Spahr and Dorman, 2004, Bassim et al., 2005, Amoodi et al., 2012). Secondly, when a recipient receives the highest possible score during the earlier assessments, identifying the further changes in their performance over time will become a problem. A recipient's performance may continue to improve; however, the test is not sensitive enough to capture the subsequent improvements (Amoodi et al., 2012, Dowell et al., 2004, Lenarz et al., 2012, Gifford et al., 2008).

Furthermore, postoperative speech outcomes are used to set the audiological candidacy criteria. Dowell et al. (2004) reported the distribution of postoperative scores, recommending that those with preoperative scores in the lowest quartile be considered potential candidates for a CI. This analysis provided an estimate of postoperative speech perception based on the preoperative score. This approach remains valid if there is a wide distribution of postoperative scores. However, if postoperative scores cluster towards the maximum –as will be shown– the model loses its specificity. Hence, clinicians and researchers are urged to continuously examine the appropriateness of the speech test battery utilised, to determine changes in the recipients' performance (Gifford et al., 2010, Amoodi et al., 2012, Spahr et al., 2014).

The City University of New York (CUNY) sentence test (Boothroyd et al., 1985) is used as a part of the pre- and post-operative test battery to evaluate speech perception of adult CI candidates and recipients in English speaking countries including Australia (Wong et al., 2014, Greenberg et al., 2011, Dowell et al., 2004, Matterson et al., 2007, Budenz et al., 2011). Although a few studies have documented ceiling effects with the CUNY sentence test when comparing different speech coding strategies (Koch et al., 2004) or different speech processors (Bassim et al., 2005, Spahr and Dorman, 2004), there are very few reports of speech scores with CUNY sentence test over time(Wilson and Dorman, 2008).

The purpose of this study was to evaluate the CUNY sentence test scores over time in a large cohort of post-lingually deafened CI recipients. We hypothesised that ceiling effects can be observed with CUNY sentence scores as early as three months post-implantation.

Methods and Material

Patient selection criteria

The database of a large cochlear implant clinic (Ear Science Institute Australia-Hearing Implant Centre) was examined to identify post-lingually deafened adult CI recipients who spoke English as their first language. The dataset was restricted to those who were implanted and received rehabilitation services between 2012 and 2014. Patients with retro-cochlear problems and abnormal cochlear anatomy (N=3) and non-users (N=2) were excluded to form as homogenous sample as possible. Ears that were reimplanted (N=5) and bilateral users who had the contralateral ear implanted outside the selected time frame (N=3) were also excluded as these potentially confuse calculating the length of the post-operative period. Only those recipients with pre-operative and at least one post-operative score were included. The resultant study cohort consisted of 117 patients (140 ears), mean age at implantation 66 years (SD: 15.09; range 23 to 98 years), 64 males and 53 females, and 21 bilateral (mean age: 64.9; SD: 14.59) and 98 unilateral (mean age: 67.9;SD: 14.39) users.

Cochlear implant device information

All recipients were implanted with either MED-EL (Innsbruck, Austria) or Cochlear (Sydney, Australia) implants. MED-EL recipients used either Rondo or Opus II speech processors and Cochlear recipients used CP810 or CP910 speech processors.

Speech test data

All available CUNY sentence test scores in quiet were collated. All assessments were conducted at a calibrated presentation level equal to 65 dB SPL (A-weighted). Bilateral and bimodal users were tested ear specific and bilaterally; however, only the ear specific results were included in the data analysis.

Data Analysis

Ceiling definition

In the psychometric function of a speech test, ceiling-level performance is the region where performance plateaus (Mackersie, 2002). In some of the studies on CI recipients, ceiling was considered the highest score on a test, that is 100% (Gifford et al., 2008, Lenarz et al., 2012), whilst others used a cut-off of 95% (Helms et al., 2004).

Aligned with the previous studies on ceiling effects with speech tests in CI recipients, in this study, it was decided to analyze ceiling scores as defined at two different cut offs, at 95% and 100%.

Statistical method

Data were tabulated in Microsoft Excel 2011 (Microsoft®, Washington). The percentage of ceiling scores was calculated for four time points: pre-operative, and 3, 6 and 12 months post-operative for all of those in the cohort. A separate analysis was conducted for those who had a complete set of scores pre-operative through to 12 months (Table 1).

Table 1. *Number of available and missing tests at each point of evaluation time.*

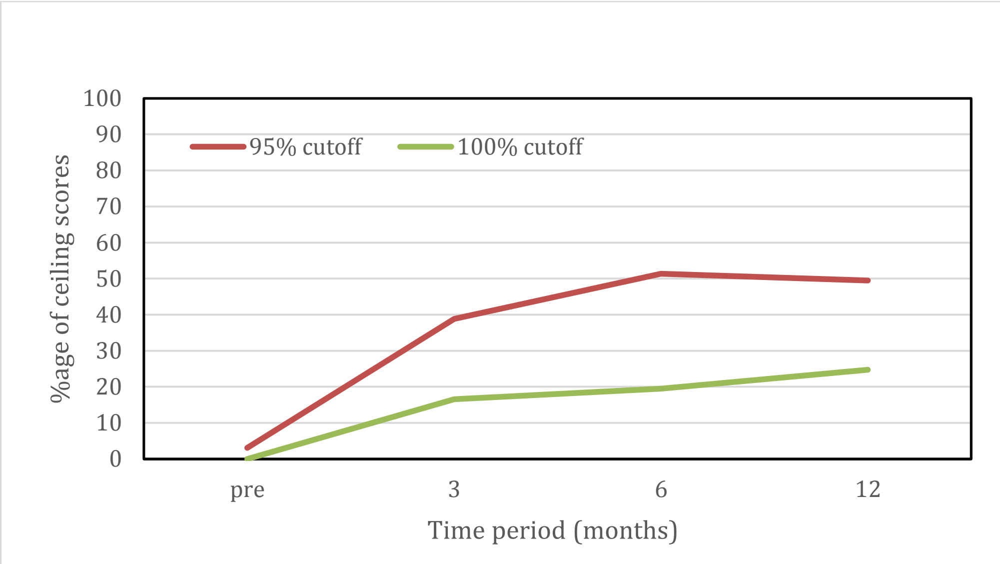
Time	Available test scores	Missing test scores
Pre-op	140	0
3 months	124	16
6 months	116	24
12 months	97	43

Descriptive statistics using the Chi-square test and the Spearman's test of association in SPSS v23 (IBM Corp. New York) were used to examine the associations between ceiling scores at each time point and the independent variables of gender, age, and uni- or bilateral implantation. The Spearman's test of association was used because the data were not normally distributed.

Results

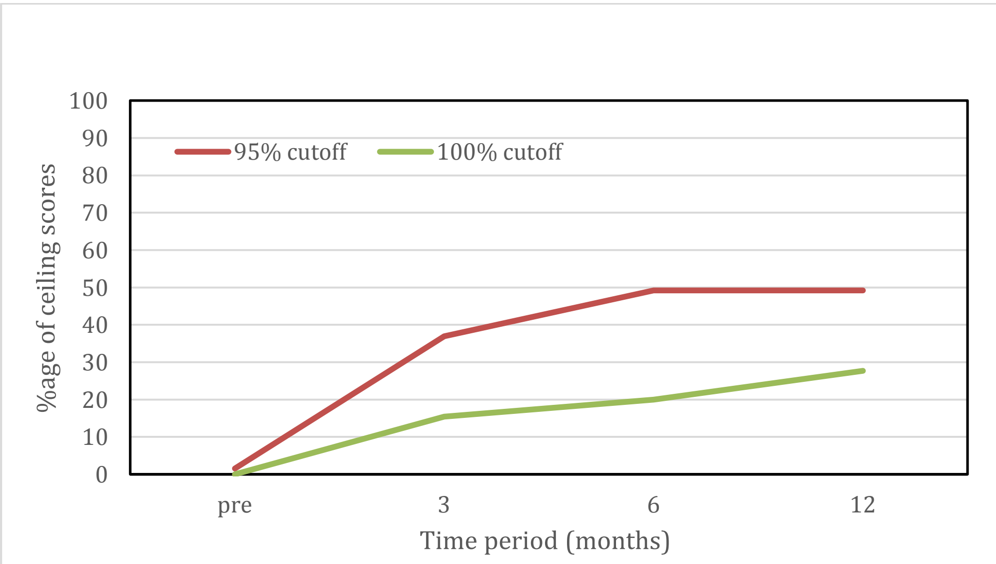
Analysis of the CUNY sentence test scores showed that in 38.8% (n=47) of cases the 95% ceiling scores was reached at three months, increasing to 51.3% at 12 months post-implantation (Figure 1). When a strict criteria of 100% was used as the cut-off, 16.5% cases reached the ceiling score at three months and 24.7% at 12 months post-implantation.

Figure 1. *Percentage of CUNY ceiling scores over time at various cut-offs.*



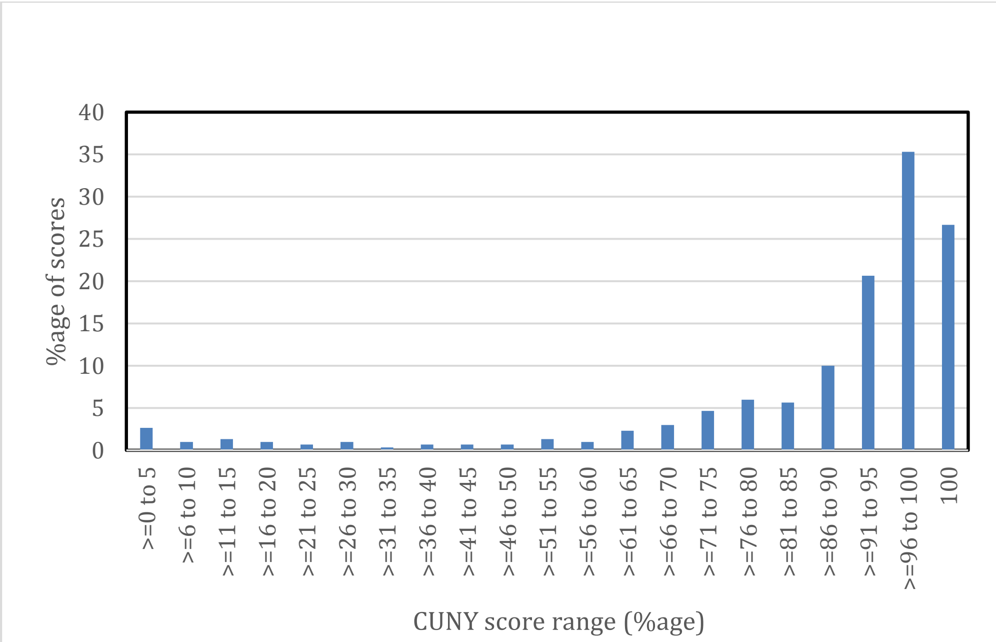
Sixty five ears were tested at all evaluation points, pre-to 12 months post-implantation. These showed very similar findings with an increasing rate of ceiling scores over time (Figure 2).

Figure 2. *Percentage of ceiling scores over time at various cut-offs for those recipients (n=65) with CUNY scores pre-operatively, and at 3, 6 and 12 months.*



The distribution of CUNY scores post-implantation in 380 instances strongly tends towards scores over 90%, with 82% of the recipients scoring above 90% while only 9.1% of the scores were below 50% (Figure 3).

***Figure 3**. Distribution of the CUNY sentence scores evaluated at 3-12 months post implantation (n=380).*



A Chi-square test for association between the number of ceiling scores and the independent variables of gender and uni- or bilateral implants was conducted. The analysis was conducted with the cut-off set at 95% and 100%. There was no statistically significant association between bilateral and unilateral recipients in reaching ceiling scores at three and six months post implantation (Table 3). However, there was a significant difference in number of ceiling scores between unilateral and bilateral users at 12 months post implantation, X^2 (1)=4.064, *P*=0.044 at 100% cut-off, and similarly at 95% cut-off (X^2 (1)=6.558, *P*=0.010). There was no statistically significant association between gender and ceiling scores at three (X^2 (1) 0.277, *P*=0.599), six (X^2 (1)=0.295, *P*=0.587), and 12 months post implantation (X^2 (1)=0.379, *P*=0.538).

Table 2. *Pearson Chi-square values and P values for association between bilateral and unilateral CI users and CUNY ceiling score counts with cut-offs of 95% and 100% at 3, 6, and 12 months post-implantation.*

Time point post implantation (months)	**95% cut-off**		**100% cut-off**	
	X^2 (1)	Significance (2 sided)	X^2 (1)	Significance (2 sided)*
3	0.555	0.456	0.731	0.392
6	0.235	0.628	0.151	0.698
12	6.558	0.010*	4.064	0.044*

*Significant at P<0.05

A Chi-square was also performed to evaluate the association between the ceiling scores and bilateral and unilateral recipients for those that had the data available at all points of testing. There was no statistically significant association between number of 95% or 100% ceiling scores between the bilateral and unilateral recipients at three, six or 12 months post-implantation.

Table 3. *Pearson Chi-square values and P values for association between bilateral and unilateral CI users and CUNY ceiling score counts with cut-offs of 95% and 100% at 3, 6, and 12 months post implantation for 65 recipients tested at all testing points.*

Time point post implantation (months)	**95% cut-off**		**100% cut-off**	
	X^2 (1)	Significance (2 sided) *	X^2 (1)	Significance (2 sided)*
3	0.044	0.834	0.492	0.483
6	0.369	0.543	0.016	0.899
12	2.626	0.105	2.510	0.113

*Significant at P<0.05

Spearman's test for association to determine the correlation between the number of ceiling scores and the independent variable of age, showed a strong negative correlation between age and the users reaching ceiling scores at three months (r_s=-0.252, *P*=0.005), six months (r_s=-0.184, *P*=0.050), and 12 months post implantation (r_s=-0.228, *P*=0.026).

Discussion

Improvements in the technology and design of cochlear implants have influenced the range and types of hearing losses that are suitable for rehabilitation with a CI, resulting in patients with more residual hearing taking up CI as a treatment option. Assessing this ever-changing population requires a test battery that is sensitive enough to evaluate the auditory and non-auditory abilities of the population.

This study retrospectively examined the rate of ceiling scores after administration of the CUNY sentence test in 117 CI recipients. It showed that as early as three months post-operatively, the number of ceiling scores was at least 16.5 or 38.8% depending on the cut-off applied, and that these generally increased over time. Dowell et al. (2004) reported CUNY scores of above 91% in almost 50% of participants. Our findings on a larger cohort of CI recipients some ten years later, show an even higher rate of recipients attaining ceiling scores with 82% of the subjects scoring above 90%.

The percentage of ceiling scores was not associated with uni- or bilateral implantees and gender as measured in this study. This finding is similar to the findings in other studies (Gifford et al., 2008, Helms et al., 2004). There was, however, an association between the bilateral users reaching ceiling scores more than unilateral users at 12 months. The reason for this is unclear, but may be related to the variability between the unilateral and bilateral users in the sample. This study also showed that the younger recipients have more ceiling scores at all points of testing than older recipients. Dowell et al. (2004) showed a similar negative association between age at implantation and postoperative CUNY sentence scores although this was not mentioned in association with the number of ceiling scores.

The high number of ceiling scores attained by recipients, draws attention to the reliability of the CUNY sentence test for use in studies to assess the long-term performance of CI users, and the validity of this assessment in clinical practice.

A number of strategies have been suggested to overcome the issue of ceiling scores in longitudinal studies and to some extent more reliably report the long-term outcomes. Counting the number of users reaching ceiling scores over time has been proposed to monitor the progress of a group of recipients (Helms et al., 2004). However, this will not show the degree of improvement over time once recipients reach ceiling scores.

Mackersie (2002) suggests that an effective way to deal with ceiling effect and increase the sensitivity of a measure is to force the scores into a steeper part of the psychometric function of a speech test by making the task, the stimuli, or both more difficult. Two alternatives can be considered, a test that adapts to changing conditions, or a more difficult test.

Adaptive tests with words and sentences have been recommended as a method to overcome the ceiling effect with speech tests in clinical settings (Soli and Wong, 2008). In a CI clinic setting, this can be effectively used to compare the conditions, devices, etc. However, the goal in candidacy assessment is to assess a potential candidate's performance in the best-aided condition at a fixed level equivalent to conversational speech. As such, an adaptive method demonstrates an inherent limitation. Some studies also suggest that an adaptive sentence test-in-quiet cannot provide reliable information on patient performance (Gifford et al., 2008).

The other approach that has been historically used in a clinical setting is to use linguistically, cognitively or contextually demanding test materials in the test battery. This approach is evident in several revisions of the test batteries to address the limitations of the previous ones (Gifford et al., 2008, Dowell et al., 2004, Luxford et al., 2001). In the most recent version of the minimum speech test battery for post-lingually deafened adult CI candidates and recipients, the Arizona Biomedical Institute sentence test (AzBio) (Spahr et al., 2012) has replaced the HINT sentence test by the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS). More linguistically demanding speech materials are used in AzBio sentence test with four different talkers (Spahr et al., 2012). Significantly fewer ceiling scores are reported and it found to be a more appropriate speech test to evaluate the current potential CI candidates compared to the previously used sentence tests (Gifford et al., 2008, Amoodi et al., 2012).

Assessing in a fixed level of noise, for example at +5 or +10 signal-to-noise ratios, has also been suggested as a more difficult task to evaluate those recipients who achieve ceiling scores in quiet (Dowell et al., 2004). However, it may be a too difficult test for majority of current potential CI candidates.

Whilst changing a test battery may be indicated, clinicians and researchers should be mindful that transition from one test to another makes the outcome measured by the previous test incomparable to the new test.

Conclusion

This study examined the variation of the CUNY sentence test in a large cohort of post-lingually deafened CI recipients. On the basis of the results presented, it is clear that a high percentage of CI users achieve ceiling scores for the CUNY sentence-in-quiet test as early as three months post-implantation.

This can limit long-term evaluation of the progress of CI recipients and the setting reliable candidacy criteria. Further study is required to examine the variability and appropriateness of alternative methods and tests in specific English-speaking population CI candidates and recipients.

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