Verbal Working Memory Error Profiles of Youth with Cochlear Implants

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ABSTRACT

Objectives: The objective of this study was to identify the types of memory errors that underlie delays in verbal working memory (VWM) in youth with cochlear implants (CIs). We hypothesized that CI users would be more likely than their normal-hearing (NH) peers to make phonological substitution errors (e.g., substituting 'M' for 'N') when recalling words from short-term verbal memory, reflecting underspecified phonological representations of words in short-term memory. Conversely, we expected that other types of errors (order errors, addition errors, and nonphonological substitution errors) would not differ between youth with CIs and those with normal hearing. **Design**: Participants were 28 pediatric long-term CI users (implanted at ≤ 3 years of age; > 7 years of CI use) aged 8-17 years and 25 NH peers who did not differ significantly in terms of age, income, gender, or nonverbal intelligence. Both samples were recruited from cochlear implant programs, hospital settings, community organizations, schools, and community settings with the same ads. The Letter-Number Sequencing (LNS) subtest of the Wechsler Intelligence Scale for Children, Fifth Edition (WISC-V) was administered in standard spoken language format by two licensed speech-language pathologists as part of a larger battery of speech, language, and neurocognitive tests. The LNS subtest is a validated VWM test that presents a random, mixed sequence of letters and numbers; subjects are then asked to recall and reorder the numbers in ascending order, followed by the letters in alphabetical order. In addition to obtaining accuracy scores for the number of correctly recalled sequences, errors were systematically coded as order errors, addition errors, omission errors, phonological and nonphonological substitution errors, and other errors. Accuracy and error scores were compared between the CI and NH samples. Correlation analyses were used to investigate associations between LNS scores and measures of speech, language, and memory within each sample. **Results**: Youth with CIs correctly recalled fewer total sequences, number sequences, and letter sequences than their NH peers. Youth with CIs made more phonological errors than NH subjects, but the samples did not differ on any other error measure. For both groups, the number of correct sequences correlated with performance on other tests of VWM. However, the number of correct sequences was associated with speech perception and language abilities in the CI sample alone. Greater numbers of phonological errors were associated with poorer speech, language, and working memory skills in the sample of CI users alone. **Conclusions**: VWM delays in youth with CIs are due in part to fragile, underspecified phonological representations of words in memory, leading to phonological errors during recall. Greater numbers of phonological errors are associated with poorer spoken language and working memory outcomes in CI users, but not in NH peers.

INTRODUCTION

- VWM is the ability to hold language information in mind simultaneously with other mental activity (Baddeley, 2012)
- VWM is assessed by presenting a language stimulus to be held in memory, along with an additional processing task
- CI users perform more poorly on measures of VWM compared to NH samples (Kronenberger & Pisoni, 2018)
- The underlying reasons for this delay in VWM in CI users have not been fully explained, but may be due to underspecified/coarsely-coded phonological representations of language in memory
- VWM performance correlates with language and other outcomes
- LNS (Wechsler, 2014) is a VWM test that presents a random mixed sequence of letters and numbers, with the goal of recalling the numbers in order of increasing quantity, then the letters in alphabetical order (Figure 1)
- LNS has multiple processing components (stimuli/items, correct order, separation of numbers/letters), any one of which could lead to errors (Figure 1)
- By identifying the specific types of errors made by CI users, we can learn what components of storage or processing are contributing to VWM delays in youth with CIs.
- Research Questions: (1) Compare youth with CIs to NH peers on LNS capacity/accuracy and types of LNS errors, and (2) identify relations between LNS scores (accuracy and error) and scores on measures of speech perception, language, and working memory

METHODS

Participants: 28 children and adolescents with CIs and 25 NH peers (Tab-1)
Inclusion Criteria: (Both groups) No developmental, cognitive, or neurologic diagnoses; oral monolingual English home; age 8-17 years; nonverbal IQ ≥ 70; (CI group) implantation at ≤ 3 years of age; > 7 years of CI use; auditory-oral communication; (NH group) hearing within normal limits
Speech Perception/Language Measures: Lexical Neighborhood Test (LNT) Total Raw Score (Kirk et al., 1995), Peabody Picture Vocabulary Test (PPVT-4) Standard Score (Dunn & Dunn, 2007), Clinical Evaluation of Language Fundamentals (CELF-5) Following Directions Scaled Score (Semel et al., 2013)
VWM Measures: WISC-V LNS Subtest (Wechsler, 2014), Visual Digit Span Forward (DSF)/Backward (DSB) Raw Score (AuBuchon et al., 2015)
Procedure:

- Standard WISC-V LNS administration and scoring
- Errors were categorized as order, addition, omission, substitution, or interference (Fig-1)
- Phonological error – Substitution of correct letter/number for inaccurate letter/number with same phoneme (Conrad, 1964; Cole et al., 1983)
- Phonologically confusable letters/numbers – E-set (BCDEGPTVZ3), A-set (AHJK8), I-set (IY59), U-set (QU2), MN-set (MN), and FSX-set (FSX)

Figure 1: LNS Error Scoring

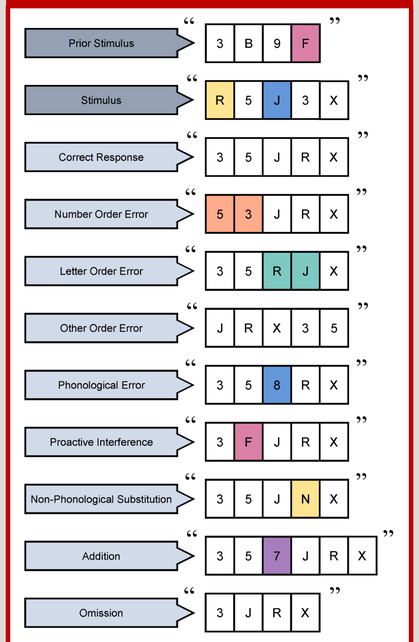

Table 1: Sample Demographics and Hearing History

	NH	CI	p
Age	11.7 (2.9)	12.3 (2.9)	0.46
Household Income	4.1 (1.6)	4.6 (2.2)	0.39
Nonverbal IQ	12.8 (3.0)	11.2 (2.9)	0.06
Gender (M/F)	16/9	18/10	1.0
Onset of Deafness	----	1.6 (3.6)	----
Duration of Deafness	----	20.1 (9.8)	----
Pre-Implant PTA in Better Ear	----	107.2 (9.0)	----
Age at Implantation	----	21.7 (9.7)	----
Duration of CI Use	----	10.5 (2.6)	----

PTA: Pure tone average; Values are mean (SD); nonverbal IQ as Leiter-3 Classification/Analogies Scaled Score (Roid et al., 2013); household income on 1-8 scale; age and duration of CI use in years; onset/duration of deafness and age at implantation in months; p-values from t-tests of CI vs NH groups, except for gender (N; Fishers exact test).

Table 2: LNS Accuracy Scores by Sample

	NH	CI	p
LNS Raw Score	17.5 (3.7)	15.0 (4.2)	0.03
LNS Scaled Score	10.6 (2.6)	8.0 (2.6)	0.001
Administered Items	23.6 (3.3)	20.7 (4.6)	0.01
Total Item Errors	6.3 (2.5)	5.7 (1.6)	0.33
Accurate Number Sequences	20.7 (4.6)	17.9 (5.1)	0.04
Accurate Letter Sequences	17.8 (3.8)	15.2 (4.3)	0.02
Number Sequence Errors (NSE)	3.0 (3.0)	2.8 (1.9)	0.80
Letter Sequence Errors (LSE)	5.8 (2.3)	5.5 (1.6)	0.48

Values are mean (SD); p-values from t-tests of CI vs NH groups.

Table 3: LNS Error Scores by Sample

	NH	CI	p
Total Memory Errors	8.3 (4.4)	8.5 (4.4)	0.83
Phonological Errors (PE)	1.4 (1.3)	2.3 (2.1)	0.08
Number-to-Number	0.0 (0.2)	0.0 (0.0)	0.29
Letter-to-Letter	0.8 (0.8)	1.6 (1.5)	0.02
Letter-to-Number	0.4 (0.6)	0.4 (0.5)	0.98
Number-to-Letter	0.3 (0.6)	0.3 (0.6)	0.81
Nonphonological Errors (NPE)	1.9 (1.7)	2.3 (1.8)	0.40
Addition Errors	0.4 (0.7)	0.2 (0.5)	0.27
Omission Errors	4.6 (4.6)	3.7 (3.4)	0.45
APE – Numbers (APEN)	0.5 (0.7)	0.2 (0.5)	0.10
APE – Letters (APEL)	0.4 (0.8)	1.1 (1.0)	0.007

APE: Accurate with phonological errors (Accurate number or letter sequence, except for one or more phonological substitution errors); values are mean (SD); p-values from t-tests of CI vs NH groups.

Table 4: Association of LNS with Measures of Speech, Language, and Working Memory

	LNT	PPVT	CELF	DSF	DSB
LNS	**0.63*****/----	**0.74*****/-0.09	**0.76*****/0.25	**0.67*****/0.36[a]	**0.41***/0.65***
NSE	**-0.32**/----	**-0.35[a]**/-0.06	**-0.41***/-0.21	**-0.12**/-0.01	**-0.10**/-0.32
LSE	**-0.05**/----	**-0.21**/-0.20	**-0.24**/-0.24	**0.18**/0.11	**0.04**/-0.31
PE	**-0.27**/----	**-0.24**/-0.23	**-0.38[a]**/-0.30	**-0.25**/-0.04	**-0.40***/0.00
NPE	**0.21**/----	**0.29**/-0.22	**0.26**/-0.12	**0.42***/0.04	**0.37[a]**/0.03
Add	**0.35**/----	**0.12**/0.16	**0.27**/-0.01	**0.55****/0.10	**0.40***/0.06
Omi	**0.23**/----	**0.22**/0.25	**0.12**/-0.58**	**0.12**/0.08	**0.23**/0.20
APEN	**-0.27**/----	**-0.14**/0.25	**-0.26**/-0.23	**-0.33[a]**/-0.13	**-0.20**/0.27
APEL	**-0.44***/----	**-0.37[a]**/-0.10	**-0.50****/0.08	**-0.47***/-0.10	**-0.49****/-0.16

Values are Pearson correlations for **CI group**/NH group; LNS: Letter-Number Sequencing Raw Score; NSE: Number Sequence Errors; LSE: Letter Sequence Errors; PE: Phonological Errors; NPE: Nonphonological Errors; Add: Addition Errors; Omi: Omission Errors; APE: Accurate with Phonological Errors-Numbers (N) or -Letters (L); [a]p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001.

DISCUSSION

- CI users had lower accuracy scores (i.e., Less sequences recalled accurately) (Tab-2)
- CI users made more letter-to-letter phonological errors (Tab-3)
- Accuracy scores were correlated with speech, language, and VWM in CI users, but VWM alone in NH peers (Tab-4)
- Isolated phonological errors (i.e., Accurate with phonological errors, APE) were negatively correlated with speech, language, and VWM in CI users, but not NH peers (Tab-4)

CONCLUSIONS

- CI users exhibited delayed VWM on the LNS test, as compared to their NH peers, due in part to a higher rate of phonological errors
- LNS performance and phonological errors were associated with measures of language, speech recognition, and VWM in CI users, but not NH subjects
- These results are consistent with the hypothesis that underspecified phonological representations of language in memory contribute to VWM delays in CI users
- Limitations include the small sample sizes and use of auditory stimuli

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