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Research Paper

Visual working memory span in adults with cochlear implants: Some preliminary findings

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Abstract *Objective:* Neurocognitive functions, specifically verbal working memory (WM), contribute to speech recognition in postlingual adults with cochlear implants (CIs) and normal-hearing (NH) listener shearing degraded speech. Three hypotheses were tested: (1) WM accuracy as assessed using three visual span measures — digits, objects, and symbols — would correlate with recognition scores for spectrally degraded speech (through a CI or when noise-vocoded); (2) WM accuracy would be best for digit span, intermediate for object span, and lowest for symbol span, due to the increasing cognitive demands across these tasks. Likewise, response times, relating to processing demands, would be shortest for digit span, intermediate for object span, and longest for symbol span; (3) CI users would demonstrate poorer and slower performance than NH peers on WM tasks, as a result of less efficient verbally mediated encoding strategies associated with a period of prolonged auditory deprivation.
Methods: Cross-sectional study of 30 postlingually deaf adults with CIs and 34 NH controls. Participants were tested for sentence recognition in quiet (CI users) or after noise-vocoding (NH peers), along with WM using visual measures of digit span, object span, and symbol span.
Results: Of the three measures of WM, digit span scores alone correlated with sentence recognition for CI users; no correlations were found using these three measures for NH peers. As predicted, WM accuracy (and response times) were best (and fastest) for digit span, intermediate for object span, and worst (and slowest) for symbol span. CI users and NH peers demonstrated equivalent WM accuracy and response time for digit span and object span, and similar response

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times for symbol span, but contrary to our original predictions, CI users demonstrated better accuracy on symbol span than NH peers.
Conclusions: Verbal WM assessed using visual tasks relates weakly to sentence recognition for degraded speech. CI users performed equivalently to NH peers on most visual tasks of WM, but they outperformed NH peers on symbol span accuracy. This finding deserves further exploration but may suggest that CI users develop alternative or compensatory strategies associated with rapid verbal coding, as a result of their prolonged experience of auditory deprivation.

Introduction

Cochlear implants (CIs) successfully restore audibility to postlingually deaf adults with moderate-to-profound sensorineural hearing loss; however, a large degree of variability exists in the speech and language processing skills among these patients. Much of this variability cannot be predicted or explained. A focus of our lab is investigating this outcome variability, in hope of developing better methods to prognosticate performance, explaining why some patients demonstrate poor performance with their devices, and improving rehabilitative efforts for this expanding patient population.

To achieve these goals, we have sought to identify and understand the complex neurocognitive mechanisms that underlie speech and language processing in adult CI users. Neurocognitive functions have been demonstrated to be a major source of individual differences among older adult CI users, in part because these functions generally show aging-related declines in the elderly.[1] Moreover, a wealth of literature demonstrates the impact of neurocognitive functions on speech recognition performance in adults with milder degrees of hearing loss.[2,3]

Working memory (WM) is one specific neurocognitive function that has been targeted for its contributions to speech and language outcomes in both pediatric and adult CI users. WM is a temporary storage and processing mechanism whereby information is held in conscious awareness while additional manipulation of that information occurs (i.e., perceptual processing, retrieval of information from long term memory).[4–6] WM serves a vital role in maintaining information for recognizing and comprehending spoken language. There is abundant evidence that WM capacity has a critical role in speech and language skills in pediatric CI users.[7–9] The role that working memory plays in speech skills among adult CI users has received some attention with regard to word and sentence recognition and sentence comprehension, but remains poorly understood.[10–12]

A barrier to further progress in our understanding of how WM relates to speech skills in adults and how it may be therapeutically targeted is that we do not know what the optimal method is to assess WM in this special population. The traditional method of assessing WM is through the use of measures that assess the participant's ability to recall a number of familiar items in correct serial order, known as span tasks. The most widely used version of this methodology is digit span, in which the participant is provided a list of digits (either visually or auditorily) and is asked to recall those digits in the correct forward order ("forward" digit span) or in reverse order ("backward" digit span).[13] Previous studies in adults with CIs have demonstrated inconsistent relations of digit span with speech recognition abilities. Tao et al[10] investigated WM in a mixed group of prelingual and postlingual CI users, some of whom were young adults. Scores on an auditory digit span task correlated with disyllable speech recognition in that study. Moberly et al[11] examined a group of 30 postlingual adult CI users using a similar auditory task of forward digit span. Digit span scores did not correlate significantly with recognition scores for sentences in speech-shaped noise. When it comes to the use of non-auditory measures of WM in adults with CIs, disparate findings also exist. Early studies by Lyxellet al[14,15] demonstrated relations between WM as assessed using a visual Reading Span measure and speech recognition for adult CI users. Moberly et al[16] failed to demonstrate a relation between speech recognition and WM assessed using a non-auditory visual measure of Forward and Reverse Memory taken from the Leiter-3 performance scale.[17] Thus, the first goal of the current study was to further evaluate the relation between WM using visual measures and speech recognition ability in postlingual adults with CIs, as well as normal-hearing (NH) peers listening to spectrally degraded (noise-vocoded) speech.

Previous studies investigating WM in CI users have identified deficits in WM capacity for patients with CIs, as compared to their NH peers. Again, most of this work has been done in pediatric CI users, who typically demonstrate poorer WM when tested with auditory as well as visual measures of WM capacity.[7,8] In contrast, studies in adults have shown equivalent performance in CI users and NH peers using visual Reading Span,[15] and only slightly poorer performance on visual versions of Forward and Reverse Memory tasks from the Leiter-3 and auditory measures of digit span and serial recall of monosyllabic words.[11,16] It is likely that discrepancies in findings between studies are a result of the particular clinical populations examined, but also the specific WM measures chosen. This concern motived the second goal of this study: to compare WM capacity between adult CI users and NH age-matched peers using three different measures of WM. Visual measures of WM were selected to avoid the confounding factor of variability in audibility and spectro-temporal resolution among participants.

Three visual measures of WM were selected for inclusion in this study. First was a visual version of the traditional digit span measure, delivered using a computer touch screen. Based on previous findings, we predicted that visual digit span measures would be equivalent between CI and