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Working memory, short-term memory and reading proficiency in school-age children with cochlear implants

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ABSTRACT

Objective: The objective of the study was to examine short-term memory and working memory through both visual and auditory tasks in school-age children with cochlear implants. The relationship between the performance on these cognitive skills and reading as well as language outcomes were examined in these children.

Methods: Ten children between the ages of 7 and 11 years with early-onset bilateral severe-profound hearing loss participated in the study. Auditory and visual short-term memory, auditory and visual working memory subtests and verbal knowledge measures were assessed using the Woodcock Johnson III Tests of Cognitive Abilities, the Wechsler Intelligence Scale for Children-IV Integrated and the Kaufman Assessment Battery for Children II. Reading outcomes were assessed using the Woodcock Reading Mastery Test III.

Results: Performance on visual short-term memory and visual working memory measures in children with cochlear implants was within the average range when compared to the normative mean. However, auditory short-term memory and auditory working memory measures were below average when compared to the normative mean. Performance was also below average on all verbal knowledge measures. Regarding reading outcomes, children with cochlear implants scored below average for listening and passage comprehension tasks and these measures were positively correlated to visual short-term memory, visual working memory and auditory short-term memory. Performance on auditory working memory subtests was not related to reading or language outcomes.

Conclusions: The children with cochlear implants in this study demonstrated better performance in visual (spatial) working memory and short-term memory skills than in auditory working memory and auditory short-term memory skills. Significant positive relationships were found between visual working memory and reading outcomes. The results of the study provide support for the idea that WM capacity is modality specific in children with hearing loss. Based on these findings, reading instruction that capitalizes on the strengths in visual short-term memory and working memory is suggested for young children with early-onset hearing loss.

1. Introduction

Auditory deprivation as a result of early-onset severe-profound hearing loss impacts development of speech production, language growth, and academic achievement. While advancements in technology and intensive rehabilitation efforts have led to large improvements in academic achievement in children with cochlear implants (CI), they still continue to lag behind their peers in reading-related measures such as vocabulary acquisition, phonological awareness skills, and reading comprehension [1,2]. One notable reason for this is that severe-profound hearing loss during early years may lead to reorganization in the pre-frontal cortex and possibly decreased maturation in the fronto-temporal regions leading to limitations in the executive functions such as working memory and planning [3]. In typically developing children, executive functions are shown to be critical for the development of reading skills, including basic reading skills, phonemic

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awareness, or reading comprehension [4]. In an effort to improve long-term literacy outcomes for children with hearing loss, researchers are exploring the relationship between short-term memory (STM), working memory (WM) and reading measures.

Short-term memory (STM) capacity, also called immediate memory capacity, is the amount of information that can be retained at any given time in one's mind. Working memory capacity or span (WM) involves an active system where information is held in mind, internalized, assembled, manipulated or transformed somehow, and then recalled or used in its new format. STM and WM are impacted by the type of task and modality (verbal or visual) being used to measure it [5]. For example, on STM word span tasks, more short words can be recalled than long words. In addition, word span capacity is linearly related to the speed at which words can be repeated and to phonological similarity [6]. While WM is a limited capacity system, there is substantial variation in working memory across individuals, and one's capacity or span varies with the type of information to be recalled. The capacity of WM increases across childhood with marked increases between the ages 5 and 11 years and smaller increases until age 15 at which time most children reach adult working memory capacity. In general, children with poor WM tend to perform poorly on all working memory tasks, regardless of modality (verbal or visual) [6].

Baddeley and colleagues multicomponent model is currently the modal model for working memory [7]. This model views memory as a processing oriented construct and conceptualizes it as the work space of the mind where active processing and the temporary storage of information take place [5,7]. The model consists of four largely independent components; a central executive, an episodic buffer, the phonological loop, and the visual spatial sketchpad. According to Baddeley, the central executive is a pure processing system without any storage function but with responsibility for higher level cognitive processes [7]. The central executive presides over the two subordinate systems of the phonological loop and the visual spatial sketchpad. Baddeley's description of the central executive appears to be similar to what many researchers are currently labeling as “executive functions” or “working memory” [5,7]. Baddeley uses both terms (executive function and WM) to explain the same concepts within his model [7]. The phonological loop is the mechanism for verbal WM, whereas the visual–spatial sketchpad is the mechanism for visual and spatial WM. The episodic buffer is a recent addition to the model and it is where modality based representations are extracted and integrated [8]. It is a limited capacity storage system capable of temporarily holding and manipulating information, but its principle function is integration [5].

Memory skills are important for all academic tasks, but are particularly critical for the development of reading skills in typically developing children. For example, WM has been shown to correlate with reading comprehension at all ages and short-term immediate memory has been related to reading comprehension at the secondary level and the prediction of later reading achievement [4]. Research indicates that the correlation of WM and reading increases with age.

Given the relationship between memory and literacy skills in typically developing children, a few studies have examined the relationship between cognitive skills and reading proficiency in children with CI. For example, verbal STM and verbal WM skills have been shown to be associated with growth in vocabulary and language comprehension in young children with CI [9]. Additionally, verbal memory capacity at 8–9 years of age in children with CIs was shown to be a strong predictor of language outcomes in those same children in adolescence [10]. Furthermore, Johnson and Goswami demonstrated that verbal STM (as measured by forward digit span) and visual STM (using memory screen from the Leiter-R) were both correlated with reading comprehension scores for children with CI [2]. In a longitudinal study, Harris and colleagues also showed that verbal STM and verbal WM at baseline predicted language outcomes in children with CIs between the ages of 6 and 16 years [11]. Overall, studies investigating the role of cognitive functions in reading outcomes in children with CI are quite limited. Thus it is not only important to continue examining the profile of STM and WM skills in young children with CI but also to assess how these skills impact reading ability.

1.1. Auditory (verbal) WM and STM

Studies have identified both strengths and weaknesses in working memory (WM) and STM skills of children with hearing loss [12,13] Specifically, studies have shown deficits in digit span and non-word repetition measures and shorter verbal memory spans in children with CI [14,15]. More recently, Harris and colleagues compared cognitive functions in children with CI to their normal-hearing peers [11]. They showed that 50.5% of children with CI in their sample scored >1SD below the mean on a digit span forward task while 44% of children with CI in their sample scored greater than one standard deviation (>1SD) below the mean on a digit span backward task. Harris and colleagues concluded that verbal STM and verbal WM are lagging in children with CI. Similarly, Nittrouer and colleagues examined both STM and WM in children with CI and their hearing peers in a serial-recall task of rhyming and non-rhyming nouns [16]. They found that recall of list order was significantly poorer for children with CIs, but serial position effects and response rates used to assess processing were not significantly different from those of their hearing peers. This supported the authors' hypothesis that the WM challenges for students with CIs are issues of storage (STM) not processing (WM). They concluded that only storage capacity was affected in children with CIs and that this was due to poor access to the phonological structure of words.

Limited access to phonological structure is expected given the impoverished input children receive through their CI [16]. Despite this disadvantage some children with early CI are attaining comparable level of performance on certain reading tasks when compared to their hearing peers. For example, Johnson and Goswami showed that children with CI had significantly poorer phonological awareness and verbal STM skills compared to their hearing controls [2]. Surprisingly, they attained similar absolute levels of word recognition and reading comprehension compared to the younger hearing controls. Johnson and Goswami suggested that these results might indicate that factors in addition to phonological awareness and auditory memory were supporting reading development for children with CI [2]. These included speechreading skills, speech intelligibility and visual memory. Johnson and Goswami hypothesized visual memory may be a strength in children with CI [2]. This view is consistent with the findings of Charlier and Leybaert that children with hearing impairments are able to develop phonological awareness skills through visual information provided from speech reading and by making gains in their speech intelligibility [17].

1.2. Visual WM and STM

In contrast to findings of limitations in auditory WM and STM skills in children with CI, studies have shown strengths in the area of visual WM and STM skills. For instance, Willis, Goldbart and Stansfield compared the verbal STM (nonword and real word recall) and visual WM abilities in 6 children ages 8–15 years with hearing impairment and significant language learning difficulties [18]. The data were gathered over a 2-year period and were