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Executive function in everyday life: implications for young cochlear implant users

Jessica Beer[1], **William G Kronenberger**[2], and **David B Pisoni**[1,3]

[1]DeVault Otologic Research Laboratory, Department of Otolaryngology – Head and Neck Surgery, Indiana University School of Medicine, Indianapolis, IN, USA

[2]Department of Psychiatry, Indiana University School of Medicine, Indianapolis, IN, USA

[3]Speech Research Laboratory, Department of Psychological and Brain Sciences, Indiana University, Bloomington, IN, USA

Introduction

Cochlear implants (CIs) provide significant speech and language benefits to many prelingually deaf children (Geers *et al*., 2008). However, CIs do not provide optimal benefits to all children who receive them. Identification of pre-implant predictors of CI outcomes is critical to providing appropriate expectations to parents and in decision making regarding intervention, assessment, management, and focused habilitation throughout childhood.

A growing body of research findings suggests that deafness and degraded auditory experience may affect not only speech and language skills, but also other neurocognitive functions (Pisoni *et al*., 2010). We adopt the working hypothesis (supported by recent findings from our center) that many profoundly deaf children who use CIs, especially the low-performing users, may have other neural, cognitive, and affective sequelae resulting from a period of auditory deprivation combined with a delay in language development before implantation. For example, compared to hearing peers, young CI users show differences in short-term and Working Memory capacity and have slower processing speeds for rehearsing and retrieving verbal information (Pisoni *et al*., 2010). Robust speech perception and spoken language processing are highly dependent on these underlying core neurocognitive building blocks.

Executive function (EF) is an umbrella construct from research in neuropsychology and cognitive neuroscience representing a complex set of cognitive processes such as organization, planning, working memory, inhibition, and flexibility, involved in the control of thought, action, and emotion (Gioia *et al*., 2001). There is general agreement among cognitive psychologists and neuroscientists that several different aspects of EF play important roles in language perception and production via top-down feedback and control of processing activities in a wide range of behavioral tasks (Pisoni *et al*., 2010). In addition, language itself serves an EF because through verbal mediation processes it can be used by the child to exercise control over thoughts, actions, and emotions with self-directed speech (Muller *et al*., 2009). For these reasons, knowledge of the developmental relations between EF and language processes in children with CIs is critical to understanding not only outcomes proximal to language, but also more distal outcomes such as learning, self-

Correspondence to: Jessica Beer, Department of Otolaryngology – Head and Neck Surgery, Indiana University School of Medicine, Riley Research 044, 699 Riley Hospital Drive, Indianapolis, IN 46202, USA. jesbeer@indiana.edu.

regulation, and social cognition. The two objectives of this study were to identify areas of EF vulnerability in children with CI's using a behavior rating scale completed by parents, and to determine if these areas of vulnerability are associated with conventional speech and language outcomes.

Methods

Participants and materials

Participants were 45 CI users aged 5.5–18.0 with a duration of implant use ranging from 5 months to 13.9 years. All children were implanted prior to the age of 7 (Table 1).

Executive function—EF was assessed with the parent report form of the Behavior Rating Inventory of Executive Function (BRIEF™). Parents indicate how often their child has experienced problems related to eight domains of EF: inhibitory control, shifting behavior, emotional control, initiating tasks and ideas, working memory, planning and organizing, organization of materials, and monitoring. Three index scores are calculated from the 8 clinical scales on the BRIEF: (1) Behavioral Regulation Index; (2) Metacognitive Index, and (3) Global Executive Composite. Raw scores are converted to T-scores based on a normative sample of typically developing, hearing children; higher scores correspond to greater executive difficulties and/or delays. Scores above 60 are considered elevated. BRIEF T-scores were used in the one-sample *t*-tests. Because we controlled for chronological age, BRIEF raw scores were used in all regression analyses. Due to the wide age range and duration of CI use of the children, we were not able to obtain scores on all speech and language measures for each child, and therefore, the sample size for each regression model varied.

Speech and language General language ability was assessed with the Clinical Evaluation of Language Fundamentals fourth edition (CELF-4) core language score (M = 100, SD = 15). Vocabulary was assessed with the Peabody Picture Vocabulary Test (PPVT-4) raw score. Open-set word recognition was assessed with the *Lexical Neighborhood Test (LNT)*, a measure of recognition of monosyllabic words presented using digital recordings of lexically easy and hard word lists. The *Hearing in Noise Test for Children (HINT-C)* was used to assess open-set sentence recognition in quiet and noise (+5 dB SNR).

Results

There were no significant differences in EF based on any of the participant descriptives provided in Table 1. Means and standard deviations for the BRIEF scales and indexes are presented in Table 2. Using a one-sample *t*-test based on hypothesized risk of poorer EF in children with CIs, children with CIs scored significantly higher than the normative mean T-score of 50 on the Inhibit and Working Memory scales and on the Behavioral Regulation Index, t (44) = 2.12, P = 0.040; t (44) = 2.08, P = 0.044; and t (44) = 2.07, P = 0.045, respectively. The percent of implanted children with BRIEF T-scores of 60 or higher ranged from 13 to 31% (16% would be expected in a normal distribution).

Six regression analyses were performed with BRIEF Working Memory and chronological age as predictors of scores on the speech and language measures. We chose the Working Memory scale as a predictor based on research from our center demonstrating significant correlations between digit span measures of working memory and speech, and language outcomes (Pisoni *et al*., 2010). In these regression equations (Table 3), BRIEF Working Memory scores were negatively related to general language ability and sentence recognition in noise, indicating that children with more working memory difficulties scored lower on those speech–language measures.

Discussion

The results of this study indicate that children with CIs have difficulty in some EF domains, based on parent report. Furthermore, these difficulties are related to their performance on some speech and language outcome measures. Children's scores on the Inhibit and Working Memory scales, as well as the Behavioral Regulation Index, were significantly higher than the normative mean, along with a greater than expected percentage of children with scores in the elevated range. The Inhibit scale assesses a child's ability to resist an impulse and also reflects a child's ability to disregard distracting information. The Working Memory scale assesses a child's ability to hold information in mind for a short period of time to complete a behavioral task such as following instructions with more than two steps, or a mental manipulation task. Both inhibitory control and working memory are core neurocognitive processes heavily mediated by language. Internal speech is often used to self-regulate by organizing and controlling thoughts prior to acting upon them; language delays may negatively impact the self-regulatory function of language on behavior. Because EF and language are components of a highly interconnected processing system, both of which are affected by a period of auditory deprivation, children with CIs might have more difficulty in speech perception and spoken language tasks that require more executive resources (Pisoni *et al*., 2010).

Our second objective provided support for this hypothesis. We found that problem behaviors related to working memory predicted children's performance on tests of general language (CELF-4) and speech perception in noise (HINT-C in noise), but not on receptive vocabulary knowledge (PPVT), perception of single words (LNT), or speech perception in quiet (HINT-C in quiet). A domain-specific content area such as hearing in noise is regulated by a child's ability to focus attention on the speech signal, while simultaneously inhibiting the distracting noise; and to correctly encode, store, and reproduce words in the sentence – all of which are controlled by executive processes. Conversely, vocabulary knowledge and repetition of single words (as opposed to sentences), does not demand the same type of cognitive control and multitasking operations. Deficits in working memory may become a problem when the task at hand carries with it a high cognitive load such as hearing in noise, perceiving spoken sentences, and formulating sentences based on a picture. Successful performance on these tasks requires the combination and integration of several neurocognitive processes such as inhibition, auditory attention, and working memory, which may stress an already vulnerable executive system and lead to poor performance. Similarly, the CELF and HINT-C in noise require integration of more complex linguistic structures over a sequence of words that places additional demands on sequential processing and verbal rehearsal, key features of the phonological loop (Conway *et al*., 2009).

In summary, using a parent report measure of problem behaviors related to EF in everyday life, we found that the number of implanted children with elevated scores on several clinical scales was greater than expected compared to typically developing hearing peers. In addition, deficits in EF related to working memory were associated with poor performance on traditional speech and language measures that require a great deal of cognitive control such as hearing in noise and general language. These findings contribute to growing evidence that a period of early auditory deprivation may result in differences in the development of domain general neurocognitive processes that impact domain-specific areas such as language and speech perception.

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Table 1

Sample description (*n* = 45)

Age *M* (SD)	Age at CI *M* (SD)	Duration of CI use *M* (SD)	Gender		Communication mode	
			Male	Female	Oral	Total
9.9 (3.9)	2.6 (1.5)	7.2 (3.8)	29	16	37	8

Table 2

BRIEF scale and index scores

BRIEF scale or index	*M*	SD	*P* *	% children elevated**
Inhibit	53.3	10.4	0.040*	31
Shift	53.0	11.7	0.091	27
Emotional control	52.5	10.2	0.112	22
Initiate	50.6	9.5	0.674	13
Working memory	53.0	9.7	0.044*	24
Plan/organize	51.6	11.3	0.359	24
Organization of materials	50.8	10.0	0.604	18
Monitor	50.6	10.2	0.684	22
Behavioral regulation	53.3	10.7	0.045*	24
Metacognition	51.6	9.7	0.268	24
Global executive	52.5	10.0	0.101	27

* *P* values with an asterisk indicate significant difference from the normative BRIEF mean of 50.

** Elevated range is a T-score of 60 or higher (1 SD above the mean).

Table 3

Regression analyses predicting speech and language scores

Outcome measure	*n*	Beta BRIEF working memory	*t*	*P*
PPVT raw score	42	0.01	0.11	0.914
CELF core language	32	−0.41*	−2.41	0.022
LNT easy words	41	−0.03	−0.17	0.865
LNT hard words	41	0.10	0.63	0.535
HINT-C words quiet	35	−0.06	−0.32	0.751
HINT-C words noise (+5 dB)	34	−0.38*	−2.27	0.030

*$P < 0.05$.