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Measures of executive function in children with cochlear implants

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MEASURES OF EXECUTIVE FUNCTION IN CHILDREN WITH COCHLEAR IMPLANTS

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee
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LITERATURE REVIEW

Beginning a few decades ago when the cochlear implant (CI) was introduced, increased benefit was seen compared to hearing aid users with similar hearing losses. This was demonstrated first with adults and later with children. These included significant improvements in areas such as speech perception, receptive and expressive language abilities, and reading abilities (Moog and Geers, 1999; Robbins, Osberger, Miyamoto, & Kessler, 1995; Blamey, Sarant, Paatsch, Barry, Bow, Wales, Wright, Psarros, Rattigan, Tooher, 2001; Bollard, Chute, Popp, & Parisier, 1999; Miyamoto, Kirk, Svirsky, Sehgal, 1999; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999; Connor, Hieber, Arts, & Zwolan, 2000). Although all these are clear, there is still question regarding why extreme variability in outcomes of measures such as these exists in this population. This project sought to examine whether some of this variability in CI users is associated with, and thus perhaps caused by, deficits in a cognitive system referred to as executive function.

CIs are auditory prostheses directly implanted into the cochlea. They are used to electrically stimulate the eighth nerve, bypassing all original means of hearing including the outer, middle, and inner ear. These devices have been available for over 20 years, and have been shown to provide a great advantage over hearing aids to both children and adults with severe to profound hearing loss. They provide frequency and temporal cues much differently than traditional hearing and therefore do not restore normal hearing. Large amounts of research also have been conducted to show these devices do provide enough information via electrical stimulation to facilitate speech perception and acquisition.

Although CIs are essentially auditory prostheses, one of the principal benefits that should be seen in children is improved speech perception and speech and language development due to increased availability of auditory input. A large number of studies have shown that indeed children with CIs improve on a number of speech perception as well as speech and language development measures and that most children with CIs do better than most children who do not receive implants with similar degrees of hearing loss (Moog and Geers, 1999; Robbins, Osberger, Miyamoto, & Kessler, 1995; Blamey et al, 2001; Bollard, Chute, Popp, & Parisier, 1999; Miyamoto, Kirk, Svirsky, Sehgal, 1999; Tomblin et al, 1999; Connor, Hieber, Arts, & Zwolan, 2000).

However, despite these gains in speech and language performance over children with similar loses who were not implanted, children with CIs typically are not as proficient in a number of speech and language domains when compared to normal hearing children. Children with CIs often score at least one standard deviation below their normal hearing peers on measures of speech perception, language, and word recognition (Blamey et al, 2001; El-Hakim, Papsin, Mount, Levasseur, Panesar, Stevens, Harrison, 2001; Ouellet, Le Normand, & Cohen, 2001; Robbins et al, 1995; Bollard et al, 1999). Along with this general trend toward subaverage speech and language achievement, there is also large variability in development including perceptual and speech/language measures (Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000, El-Hakim, Papsin et al, 2001; Moog, Geers, 1999).

This noted variability in outcomes has been traced to a number of factors including peripheral features (e.g. capabilities of the device, how it processes information) and the auditory nerve. Children with cochlear implants differ from their normal hearing peers because of a period of auditory deprivation and the degraded auditory information available via the CI. These peripheral auditory factors and deprivation may likely lead to the language variation seen on standardized testing measures. One peripheral auditory factor that has been shown to cause variability is channel interaction between electrodes in the cochlear implant prosthesis. Research by Hughes (2008) demonstrated that both pitch ranking ability and overlap of ECAP excitation patterns were both affected by distance between electrodes in the pair being studied. Also, they found that increased separation led to increased pitch ranking abilities and decreased ECAP spatial excitation pattern overlap. Therefore, peripheral auditory factors, such as a degraded auditory signal due to interaction by overlapping excitation patterns may be playing a part in reduced speech perception as it may be more difficult to discern speakers. This consequently may result in more difficulty learning language in children with cochlear implants.

A number of other variables have been documented such as age at implantation, CI experience, and communication modality, which are also factors affecting the variability in outcomes. Recently, Fagan, and Pisoni (2010) found that children's performance on the Peabody Picture Vocabulary Test (PPVT) was related to length of experience with their cochlear implant. James, Rajput, Brown, Sirimanna, Briton, and Goswami (2005) and Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth (1997) were able to show that earlier age at implantation lead to a better outcome on measures of phonological awareness, vocabulary, reading, and open set word recognition. More growth was also seen in children with earlier implants in areas of phonological awareness. Age at implantation and oral communication modality have also been found to significantly predict speech perception performance (O'Donoghue, Nikolopoulos, & Archbold, 2000). Lastly, there are a number of other variables that have also been documented. These include variables such as nonverbal IQ, gender, and length of time with newest processing strategy (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003). Also, speech sound production after 4 years has also been found to be predictive of children's later speech sound production (Tomblin, Peng, Spencer, & Lu, 2008).

Therefore, as described above, great strides have been made in identifying causes for variability in outcomes of CI users. However, there are still children who perform poorly with their implant and no one or set of variables can yet account the difference in performance. Therefore there is more work to be done to further investigate what variables or sets of variables are impacting performance.

There may be several reasons why we are no closer to finding out why such variability is shown in outcomes of children with CIs. One reason may stem from the way researchers and clinicians measure outcomes in these children. Almost all outcomes such as expressive and receptive language, articulation, and reading ability are assessed with standardized tests such as the Peabody Picture Vocabulary Test (PPVT), the Goldman Fristoe Test of Articulation (GFTA), the Woodcock Johnson, or the Expressive Vocabulary Test (EVT). Although these tests have proven to be excellent measures in the clinic to gauge a child's performance at a certain point in time, they do not asses WHY a child does well or poorly on the test. These tests also require the child to use a variety of skills in order to participate in the tests that are not taken into consideration in testing situations. For example, in the PPVT a child must pay attention to the presented word, hold that word in memory, scan a set of visually presented pictures, and inhibit any immediate responses while deciding among the set. The child must then make a decision based on his/her knowledge of the presented item. Therefore, a vast number of additional abilities including attention, memory, scanning, and inhibition are being used to complete these seemingly simple tasks, and these abilities play a large part in the child's standardized testing outcome or in the case of the PPVT, receptive language ability. All of these abilities arise out of basic auditory experience, which directly influences language learning. In order to do well on these standardized measures, which we use to gauge children's language ability or outcome, children must also have adequate attention, inhibition, organization, planning, and working memory. Many of these abilities fall under the broad/large term of executive functions (EF) abilities.

Executive function has received increasing attention in the literature, likely due to its significant impact on everyday functioning and performance in the classroom. EF can be defined as "a group of high level processes that are involved in organizational and self-regulatory skills required for goal directed or non-automatic behavior" (Figueras, Edwards, & Langdon, 2008). Grattan & Eslinger (1992, p. 192) as cited in Marlowe (2000) defined executive function as "…cognitive and self-regulatory processes which include cognitive flexibility, impulse control, synthesis of multiple pieces of information across time and space, divergent production of ideas and alternatives, decision making, planning and regulation of goal directed activity." Therefore these abilities are important in generation of appropriate behavior and are necessary for interacting in environments where productivity and efficiency are valued, such as in the classroom. Impairments in these abilities have been documented in acquired disorders such as brain injury (Bawden, Knights & Winogron, 1985 as cited in Marlowe, 2000; Fletcher et al, 1996 as cited in

Marlowe, 2000; Levin et al, 1994 as cited in Marlowe, 2000) and in developmental disorders such as attention deficit hyperactivity disorder (ADHD, Barkely, Grodzinsky, & DuPaul, 1992 as cited in Marlowe, 2000; Denckla, 1989 as cited in Marlowe, 2000)

Because these skills are needed to perform and complete many outcomes measures used to assess children's outcomes, including language abilities, it seems probable that a relationship between executive function abilities and language abilities exists. This belief is supported in research by Im-Bolter, Johnson, and Pascual-Leone (2006) who described differences in the executive function abilities including mental attention, interruption, and updating in 45 children between the ages of 7 and 12 with specific language impairment (SLI). This research implies that deficits in language do not seem to be independent of deficits in the cognitive domain such as executive function.

As a relationship between executive function and language abilities is demonstrated, atypical development of these executive function skills such as attention, inhibition, organization and planning may be contributing to a lower performance on the standardized measures used in assessing children's language abilities. This idea is central in a large amount of research being conducted at Indiana University by David Pisoni. His research focuses around the belief that a period of auditory deprivation disrupts neural system development. Since neural systems are greatly linked with one another, disruption not only occurs in the auditory domain, but a number of others, including areas in the frontal lobe related to executive function (Pisoni in Hauser, Lukomski, & Hillman, 2008). Again, this may be because deaf children or children with severe/profound hearing losses are not exposed to the same basic auditory experience that normal hearing children are which may then directly influence their language learning ability. Due to the fact that many language abilities are unable to be tested independently of executive function, executive function abilities may be influencing scores on standardized assessments. Therefore, in order to accurately assess variability in CI outcomes, examination of the executive function abilities that may be contributing to language performance on standardized assessments should be addressed. Seeing that these abilities do play such a large role, their examination as a source of variability may help explain performance discrepancies on standardized measures among children with cochlear implants and their normal hearing peers.

This idea that executive function abilities may develop differently or even deviant in this population is posible for a number of reasons. First, it is well known that there are rich interconnections between sensory, motor, auditory, and visual signals in the brain, and that auditory input and communication are imperative for normal development of not just language, but as well cognition and behavior. If one of the sensory modalities is impaired, its likely effects will be seen in a number of other areas. The effect of a period of auditory deprivation on children with cochlear implants has been well described in a number of articles. In 2007, Sharma, Gilley, Dorman, and Baldwin described the period of auditory deprivation as a period when sensory input is unavailable during a child’s development leading to the pathways dedicated to this sensory modality unstimulated and unpruned. This leads to atypical development of the pathway because these unused pathways may be taken over by other modalities. As these other modalities begin to take over the unused region, the brain reorganizes due to a lack of auditory stimulation in the deaf child. This phenomenon was also described by Robinson (1998). He concluded that activity and use of a sensory modality leads to neural development, and a period of auditory deprivation can lead to a loss of responsiveness or possible compensation. This reorganization ability is also demonstrated in studies by Wolff and Thatcher (1990) and Kang, Lee, Kang, Lee, Oh, Lee and Kim (2004). Wolff and Thatcher (1990) showed that deaf children show less evidence of connectivity in the left auditory cortex than hearing children and correspondingly more evidence of activity in the right auditory cortex than hearing children. Kang et al (2004) also showed that PET images of the brain after cochlear implant surgery were greater in the medial visual cortex and bilateral occipito-parietal junctions than for normal hearing children. In addition, they also found that better speech perception abilities were associated with higher activity in the visual areas. Taken together, evidence supports the notion that the brain does reorganize when sensory stimulation is unavailable, such as in children born deaf or with severe/profound hearing losses.

In the case of children who have the opportunity to receive cochlear implants, this brain reorganization may occur, or start to occur as described above. As the brain begins to respond to this new stimulation, the pathways normally dedicated to this modality become committed to other uses, and competition for resources may occur. At this point, there is debate in the literature as to whether development now just becomes delayed, meaning that it remains plastic and normal development occurs, only later, or is deviant meaning it develops differently and is no longer plastic. Sharma, Gilley, Dorman, and Baldwin (2007) believe that this competition may result in abnormal sensory reception, atypical responses to multisensory input, and an overall slowness of systems after receiving a cochlear implant indicating deviant development. However, Robinson (1998) believes that these effects of inactivity can be reversed by the implantation. He believes that the plasticity remains, and that normal sensory development occurs following implantation, just a bit delayed. Robinson bases this finding off evidence linked to better outcomes in children with earlier implantation, and the fact that it appears the longer the period of deafness, the lower the level of cortical activity. Sharma, Gilley, Dorman, and Baldwin (2007) also support earlier implantation, but this group believes that there may only be a sensitive or critical period where normal development may occur. If children are not implanted before this critical period, normal development is less achievable due to more permanent reorganization.

However, whether neural development after cochlear implantation is deviant or delayed a majority of children seem to show some improvement in speech and language skills post implant. This means that children are able to use the available information to learn and adapt to a different auditory environment requiring auditory processing. Due to their changing and adapting brain, processes interconnected to this modality will likely be affected. These processes may include neural circuits involved with executive function and cognitive control processes, such as attention, inhibition, organization, and planning.

Early work has already begun to demonstrate differences between the children with CIs and normal developing children’s executive function abilities. One of the first executive function abilities looked at by researchers was working memory. Working memory is a well documented and researched ability, and it is an important part of standardized testing for a number of reasons. Working memory is vital for storing short term information such as instructions, the presented word, and possible semantic information. Pisoni and Cleary (2003) first investigated working memory and found atypical forward and backward digit span results in children with cochlear implants when compared to their normal hearing children. Children with CIs had shorter digit spans overall and their digit spans correlated with speech perception tasks such as the WIPI, LNT and BKB. Results indicated that longer digit spans correlated with increased word recognition on these tasks. This was also independent of known sources of variance including chronological age, communication modality, and duration of deafness. It was suggested that children with cochlear implants had differences in storing and maintaining verbal information in working memory. In addition, to further investigate this working memory component, Burkholder and Pisoni (2003) used a digit recall task to assess scanning of verbal information in short term memory. They found a number of differences between children with cochlear implants and normal hearing children. These included normal hearing children were able to retrieve three times faster than children with cochlear implants, and children with cochlear implants had longer pauses in between retrieved parts. These results led researchers to believe children with CIs showed slower verbal rehearsal and slower serial scanning of short term memory. This also then was associated with overall shorter digit spans in deaf children with cochlear implants.

Although working memory is one component of executive function, many other components exist as well. For example, numerous studies have addressed attention abilities in deaf individuals with and without cochlear implants. Khan, Edwards, and Langdon (2005) investigated both children's non-verbal cognition and behavior using the Leiter International Performance Scale-Revised (LIPS-R), and the Child Behavior Checklist (CBCL). They found that children with cochlear implants performed at the same non-verbal cognitive level as hearing children on every measure except attention abilities. In addition, deaf children and adults routinely have been found to have problems with attention and sustaining attention (Hauser, Lukomski, Hillman in Hauser, Lukomski, &Hillman, 2008) suggesting that attention abilities may be impacted by a period of auditory deprivation. Therefore, it seems further research is needed to understand whether children with cochlear implants exhibit problems in the domain of attention, or even more specifically visual attention.

Visual system differences have been an area of interest and research in deaf children, both with and without cochlear implants. This interest is motivated for a number of reasons, but largely because of the well documented changes in the use of the visual system, as discussed above. This is both after a period of deafness and possible reorganization both before and after receiving a CI. Also, there is accumulating evidence that children with cochlear implants have an overall impaired ability to sustain attention. Examining executive function in this population then becomes increasingly interesting because of their suspected differences and impairments in both domains. Studies have begun to investigate this ability in normal hearing and deaf children, however, no clear conclusion can yet be made. In a systematic review by Tharpe, Ashmead, Sladen, Ryan and Rothpletz (2008) it was clear that the visual system does serve a compensatory role, and helps direct extra attention to visual periphery in deaf individuals. However, there are still mixed conclusions about whether this altered organization results in better or worse visual attention abilities by those who are deaf versus their normal hearing peers. There seems to be no clear deficits or enhancements in visual function of deaf individuals in literature. So again, there are mixed results in whether auditory deprivation can affect these abilities.

Now the question becomes whether these proposed deficits are seen in children with cochlear implants, as more deaf and hard of hearing children are receiving this technology. Pisoni (Hauser, Lukomski, Hillman, 2008) at Indiana University is one researcher who has begun to explore a number of these executive function abilities. Pisoni began this research using the Neuropsychological Assessment (NEPSY) subsets of Design Copying and Visual Motor Precision. Results indicated that the mean performance was lower for children with cochlear implants compared to normal hearing children. However, Figueras, Edwards and Langdon (2008) found that there was no difference in performance on the NEPSY Tower (a test designed to assess nonverbal planning, problem-solving, monitoring, and self-regulation abilities) between 8 to12 year old children with cochlear implants, hearing aids, and normal hearing . Additionally this group also found no difference between the two groups using raw scores on the Visual Attention subset. Also, there was no difference in performance of any measure when comparing children with cochlear implants to children with hearing aids. They did however find a significant correlation between overall language score and overall EF scores, indicating again a relationship between EF abilities and language. They also indicated that better performance on the language subsets was associated with better performance on the executive function tests for both hearing and deaf children, even after age had been controlled.

These results suggest that there seems to be some impairment of these executive function abilities in children with cochlear implants as suggested previously in this review. As preliminary results suggest, there may be impairment in working memory, such as in ability to copy designs. In addition there may be impairments in visual attention abilities as assessed with the Visual Attention subset of the NEPSY. Also, it seems that there is some component or components of these abilities tied to language ability or contributing to language performance. However, the reported data from Pisoni is preliminary data. A greater number of participants would be necessary to in order to increase the power and show definitive results. In addition, there has not been a great deal of research devoted to this area and examining executive function through these standardized measures. Therefore, further analysis and replication is warranted.

In conclusion, further research needs to be conducted to support/oppose these preliminary findings and investigate other areas of EF. This includes assessing executive functions in another way. There have typically been two ways to reliably assess executive function, one through behavioral measures, as discussed above, and one through parent report measures. Behavioral measures include tests such as the NEPSY and LIPS-R. An example of a parent report measure would include the Behavior Rating Inventory of Executive Function (BRIEF). This is a standardized parent questionnaire that has been normed on parents, caregivers, and teachers. It has also been shown in the literature to be a valid and useful measure in assessing executive function (Gioia, Isquith, Guy, & Kenworthy, 2000; Bodnar, Prahme, Cutting, Denckla, & Mahone, 2006). Recent preliminary data also have been collected on children with cochlear implants using this measure by Pisoni. When comparing children with cochlear implants to normal hearing children, he found that children with cochlear implants had elevated scores in the Behavioral Regulation Index, the Metacognition Index, and the Global Executive Composite divisions of the BRIEF parent questionnaire. He also found CI children to have significant differences on the individual subsets that pertain to shifting ability, emotional control, and working memory (Pisoni in Hauser, Lukomski, & Hillman, 2008)

In addition to the BRIEF, Pisoni (Hauser, Lukomski, & Hillman, 2008) also collected two additional parent questionnaires. These included the Learning Executive and Attentional Functioning Scale (LEAF) and the Conduct-Hyperactive Attention Oppositional Scale (CHAOS). These are two parent report questionnaires that assess children’s executive function abilities. However, these two questionnaires to date have no normed data collected, so raw scores can only be used to compare data between groups. When Pisoni (Hauser, Lukomski, & Hillman, 2008) collected preliminary data regarding these two questionnaires, he found significant differences in attention, hyperactivity, and opposition problems on the CHAOS and learning, memory, attention, speed of processing, sequential processing, complex information processing, and novel-problem solving differences on the LEAF. These results again indicate possible differences in executive function abilities per parent report on a number of different components.

Although these data show promise in a number of areas, there are also many problems. First, Pisoni (Hauser, Lukomski, & Hillman, 2008) collected the above data as preliminary work and therefore collected the data with a small subject population (small *n).* Therefore, replication or supplemental research with normal hearing and children with cochlear implants needs to be completed in order to determine if these executive function impairments are seen in children with cochlear implants. Additionally, no study to date has addressed if parent report and behavioral measures of executive correlate, and actually measure the same possible impairment. This is important as both are typically accepted measures of determining if differences exist between the groups. Therefore, this study aims to either replicate or contradict findings regarding executive function impairment in children with cochlear implants. In addition, it proposes to be the first of its kind to address the relationship between parent report EF measures and behavioral based assessment of these abilities.

METHODS

Participants

Participants in this investigation included 33 (18 male and 15 female) children with cochlear implants with age ranges between 6 years; 10 months and 12 years; 6 months (M=9 years; 9 months). A total of 15 children had sequential bilateral implants and 18 had unilateral implants. These children were followed longitudinally by the University of Iowa's Cochlear Implant Research Program. All children with cochlear implants in this investigation had prelingual hearing loss with no additional disabilities. Children received their first cochlear implant between the ages of 11 months and 10 years; 3 months (M=2 years; 7 months). Duration of cochlear implant use from first implant ranged from to 11 months to 11 years of age (M=7 years; 2 months).

Children with normal hearing included 29 (10 male and 19 female) children between the ages of 6.25 years and 12.33 years (mean= 9.5 years of age). Normal hearing children were recruited by advertisement and word of mouth. All children spoke English as their first language.

Procedures

Each child was videotaped and tested individually during an hour long testing session. Parents were asked to fill out the Behavior Regulation Index of Executive Function (BRIEF), the Learning, Executive, and Attentional Functioning Scale (LEAF), and the Conduct-Hyperactive Attention Oppositional Scale (CHAOS) questionnaires while their child was being tested by the examiner. After the parents were given the questionnaires, the subject and examiner entered an adjacent room where a video camera recorded the session and provided the parents with viewing from an adjacent room.

Once the children were seated with the examiner in the adjacent room, they were first given the Peabody Picture Vocabulary Test-III (PPVT-III, Dunn & Dunn, 1997), followed by the Neuropsychological Assessment (NEPSY, Korkman, Kirk, & Kemp, 1998) subsets of Tower, Block Construction, and Visual Attention.

This PPVT is a receptive vocabulary measure normed on children and adults 2-90 years of age. Participants are asked to point to/say the number of the picture that best represents the given word from four pictures. Upon completion, the children's raw scores were converted to age equivalents and standard scores based on the norms provided.

After this test, the children were administered subsets of the NEPSY. This is a standardized measure normed on children between the ages of 3 and 12. The subsets chosen included the Tower, Block Construction, and Visual Attention subtests. The Tower task is designed to measure nonverbal planning, problem-solving, monitoring, and self-regulation abilities. The child is instructed to move three colored balls around on three pegs to match a picture. The child is only given a certain number of moves, and the moves must be made in accordance with a set of rules given in the instructions.

The next task, the Block Construction subset, is designed to measure visuospatial processing and the ability to reproduce pictures three dimensionally. This measure was included as a non-verbal measure, so at least one of the tasks had no possible language component. The examiner in this task instructed the subjects to manipulate their blocks in order to match the picture presented. Subjects are also given a time limit for each trial, and awarded extra points if they complete the construction in a timelier manner. Examiner also counted trials incorrect if the blocks were not constructed at an angle that resembles the angle depicted in the picture presented. For example, if the blocks were rotated 90 degrees from their correct orientation, the trial would be counted as incorrect.

The last subset administered to the subjects was the Visual Attention subtest. This subtest was designed to measure attention to a visually presented array of pictures. It assesses the speed and accuracy with which the subject is able to focus and maintain attention. Subjects were instructed to find as many matching targets as they could, with the opportunity to look back to the target at the top of the page. They were given 180 seconds for each of the two visual arrays presented. Their score was determined based on their accuracy and speed of completion. All NEPSY raw scores were converted to standard scores and age-equivalency scores based on the normative data provided.

During the standardized testing procedures, the parents/caregivers filled out the questionnaires in an adjacent room. The first questionnaire given was the BRIEF. The BRIEF is a parent questionnaire normed on children 5 to 18 years of age, and is comprised of 8 different subscales. These scales measure whether the parent/caregiver reports problems with different types of behavior related to 8 domains of executive functioning. These include inhibition, shifting ability, emotional control, initiation, working memory, plan/organizational ability, organization of materials, and monitoring ability. The parent/caregiver filling out the survey is asked to answer if their child never, sometimes, or often exhibits a behavior on the BRIEF. Example behaviors related to shifting ability include “acts upset by a change in plans,” or “thinks too much about the same topic.” Therefore, parents would be asked to choose if their child never, sometimes, or often acts upset by a change in plans (Gioia, Isquith, Guy, Kenworthy, 2000). Higher scores represent worse performance on that subset.

The data parents provide on this questionnaire can also be compiled in a number of ways. The 8 clinical scales can combine to form two indices, the behavioral regulation and the metacognition index. The behavioral regulation index encompasses inhibition, shifting ability, and emotional control. The metacognition index encompasses initiation, working memory, plan/organizing ability, organization of materials, and monitoring ability. Lastly, a summary score, the global executive composite, can also be reported. This score encompasses the whole test. Normed data also are available so that raw scores from each subscale, index, and the summary score can be converted to t-scores.

In addition to the BRIEF, parents were also given the LEAF (Kronenberger, 1996) and CHAOS (Kronenberger, Dunn, & Giauque, 1998) questionnaires which assess learning, executive function, and attention-hyperactivity. The LEAF is comprised of 55 questions with four possible responses, including 0=never, 1=sometimes, 2 = often, and 3= very often. Its questions are designed to measure a number of components, including comprehension and concept learning, factual memory for learning, attention for learning, processing speed, organization and visual-spatial skills, planning and sequential processing, processing of complex information, novel problem-solving, numeric concepts, phonological reading, and written expression. Examples include “has a poor memory,” “easily distracted,” and “poor organization.” Elevated scores on the LEAF indicate more impairment in that particular area. No normative data are available to date for this particular questionnaire, so comparisons are limited to between group analyses in this particular study.

The last questionnaire, the CHAOS, is composed of 22 questions that measure attention problems, hyperactivity, oppositional problems, and conduct problems. Example questions include “does not finish things that he or she starts,” “is easily distracted by things” and “talks too much.” Parents are asked to answer each question based on the child’s behavior during the last week with 0 = never (less than once a week), 1= sometimes (less than once a day, some days), 2= often (once or more a day, most days), 3= very often (many times every day). Both tests were developed by William Kronenberger, Ph.D., at the Riley Child and Adolescent Psychiatry Clinic (RCAPC) Attention Deficit Hyperactivity Disorder (ADHD)/ Disruptive Behavior Disorders (DBD) Clinic. Again, no normative data are available to date for this particular questionnaire, so comparisons are limited to between group analyses in this particular study.

Scoring and Reliability

All standardized tests were scored either during testing or from a videotaped session. Each test was scored initially by one researcher, and then scored again by an additional researcher to ensure accuracy in scoring and data entry. SPSS 17 was used for all statistical analysis.

RESULTS

Neuropsychological Assessment (NEPSY)

Table A2 presents the standard scores for both the children with cochlear implants and their normal hearing peers on the Tower, Block Construction, and Visual Attention subsets. Figure B1 also demonstrates this graphically. As shown in both Table A2 and Figure B1, children with normal hearing on average performed better on all three subsets than children with cochlear implants. On the Tower subtest, children with cochlear implants on average scored 8.84, while children with normal hearing scored an average of 11.86. In addition, the same trend was seen for the other two subsets, with children with normal hearing scoring an average 11.21 on the Block Construction and 11.32 on the Visual Attention while children with cochlear implants scored on average 10.42 on the Block Construction subset and 9.44 on the Visual Attention.

Results of the independent-samples T-test to evaluate differences in performance on the Tower subtest demonstrated a statistically significant difference ($p < 0.001$) between the two populations. This indicates that children with cochlear implants scored significantly lower on the Tower task than their normal hearing peers. This Tower task is designed to measure the executive function areas of nonverbal planning, problem-solving, monitoring, and self-regulation abilities, which would imply that children with cochlear implants have more problems in these areas than their peers with normal hearing.

Next, Block Construction and Visual Attention results were analyzed through independent-samples T tests. Children with cochlear implants were found to score significantly lower than their normal hearing peers on the Visual Attention ($p = 0.052$), but not on the Block Construction subtest ($p > 0.05$). The Visual Attention subset is designed to measure attention to objects presented visually in an array. Results therefore indicated that children with cochlear implants have significantly more difficulty in attending to pictures in an array than their normal hearing peers. The Block Construction task was designed specifically to measure visuospatial processing and the ability to reproduce pictures three dimensionally. Therefore, this task involved no language component, as children are just shown a picture and asked “to make theirs look just like this one.” No significant difference therefore was found between these two populations.

Vocabulary Assessment

Table A3 presents a summary of the scores obtained from the PPVT. In accordance with previous research, children with cochlear implants performed more poorly on this measure compared to their normal hearing peers. An independent-samples T-test revealed a significant difference in performance between children with cochlear implants and their normal hearing peers ($p < 0.001$). This indicates that children with cochlear implants have significantly depressed receptive vocabulary skills when compared to their normal hearing peers.

Parent Questionnaires

Behavior Rating Inventory of Executive Function (BRIEF)

Table A4 presents the means and standard deviations for the BRIEF parent questionnaire. Figures B2 and B3 also present these data in graph format. As shown from both Table A4 and Figures B2 and B3, there is no difference in performance between children with cochlear implants and children with normal hearing. When analyzing these results, no significant difference ($p<0.05$) was found between the populations on any of the subsets within the BRIEF parent questionnaire. Thus these results suggest that if there are differences in executive function between children with normal hearing and children with cochlear implants, they are not identified when using the BRIEF parent questionnaire.

Learning, Executive, and Attentional Functioning Scale

(LEAF)

Table A5 presents the means and standard deviations for the LEAF parent questionnaire. Figure B4 presents these same data in graphic form. As shown in Figure B4, results varied for each subtest. Results of independent samples T-test indicated that three subsets were identified as having significant differences between the two populations. These included concept learning ($p = 0.001$), phonological reading ($p = 0.005$), and the written subset ($p = 0.033$). These results indicate that children with cochlear implants may have a significantly harder time learning concepts and using phonological skills during reading and writing.

Conduct-Hyperactive Attention Oppositional Scale

(CHAOS)

Finally, Table A6 presents the results of the CHAOS parent questionnaire and Figure B5 represents this information graphically. As shown by both the table and the graphs, no significant difference can be indentified on any of the subsets. This indicates that children with cochlear implants may not have any impairment related to hyperactivity, oppositional problems or conduct problems. It also may be possible that these impairments are simply not picked up by this parent report measure.

<u>Age at Implantation</u>

To explore the possibility of results being influenced by additional variables, correlations investigating a relationship within the outcome measures and age of implantation also were completed. This was done because of extensive research documenting that children who are implanted earlier often perform better than children implanted later. To explore if results of the Tower subtest were related to age of implantation, a correlation was run with a result of $r = 0.132$, $p=0.470$, indicating no strong correlation between the age the child received the cochlear implant and their planning and organizational abilities. Additionally, another correlation was run to examine age of implantation relationship with results of the Visual Attention subset. These results again indicated no relationship ($r = -0.10$, $p = 0.962$).

A correlation also was run to investigate age of implantation effects on the outcome of the behavioral regulation index of the BRIEF, because this index measure yielded the most variance. However, results revealed a relationship of $r = 0.265$ ($p = 0.143$), again demonstrating no relationship between age of implantation and their behavioral regulation. A correlation was run again with the MI of the BRIEF to investigate any relationship between age of implantation and metacognition areas of the BRIEF. Again no relationship was demonstrated ($r = 0.126$, $p = 0.493$).

Lastly, the association of age of implantation was examined with respect to the scales from the last two parent questionnaires, the LEAF and CHAOS. Correlations were run between the age at implantation and the LEAF scales. Results of correlations looking at the LEAF and age at implantation showed that none of these scales were correlated with age at implantation including concept learning ($r = -0.090$, $p = 0.618$), phonological reading ($r = 0.054$, $p = 0.766$), and the written subset ($r = 0.028$, $p = 0.875$). The CHAOS was then the last parent questionnaire addressed. Results indicated that the there was no significant relationship on any of the measures of Attention ($r = -0.028$, $p = 0.876$), Hyperactivity ($r = 0.096$, $p = 0.595$), Opposition Problems ($r = 0.023$, $p = 0.898$), or Conduct Problems ($r = -0.015$, $p = 0.935$).

Lastly, to investigate whether age of implantation had any relationship or influence on the receptive language scores of the PPVT, a correlation was run investigating a possible relationship between age of implantation and the PPVT. No relationship was demonstrated ($r=0.113$, $p=0.544$). This relationship is somewhat surprising due to previous research suggesting a robust negative correlation between these two variables.

Influence of Language Ability

To explore the possible influence and relationship of language ability and EF performance, correlations were run with all subjects to identify any significant relationships between the two variables. Results of this are displayed in Table A8. Children's language performance was significantly related to their test performance on the Tower ($r = 0.606$, $p = 0.001$), Visual Attention ($r = -0.905$, $p = 0.001$), concept learning ($r = -0.604$, $p = 0.001$), phonological reading ($r = -0.516$, $p = 0.001$), and written subsets ($r = -0.545$, $p = 0.001$). This relationship was not documented with any other executive function measure. This indicates these particular measures, the same measures that significant differences between the two populations were identified originally, are significantly related to receptive language ability as measured by the PPVT. Due to this, CI children's lowered performance on the Tower, Visual Attention, conceptual learning, phonological reading and written subsets can likely be accounted for by their poorer language ability. However, this relationship is correlational and therefore it is possible that EF could me mediating language performance on these particular measures.

As described above, significant correlations were found between a number of the EF measures and the children's overall language ability. Due to the children with CIs noted poorer language ability, it is possible that the performance deficits on these tasks could reflect the language abilities of the child rather than executive function ability. Thus, further analysis was required in order to identify if language (which was measured here using the PPVT) was a factor in differences indentified in these populations.

First in order to identify whether language (PPVT score) was modulating the noted differences in the populations; language was used as a covariate in a univariate analysis of variance. Once language was controlled using this analysis, no significant differences between the two populations were found. Results are documented in Table A7. These results indicate that since no significant difference was found after language was used a covariate in the analyses, language was greatly influencing the children with cochlear implant’s ability to perform as well as their normal hearing peers on these tasks.

DISCUSSION

This study aimed to answer whether current research addressing executive function abilities in pediatric cochlear implant users was accurately depicting their impairments. Secondly, this study aimed to identify differences in identification of executive function impairments when measured using parent report versus behavioral measures of executive function. Results of each test will be first discussed, followed by an overall discussion on the results and implications.

Behavioral Measures

One way that executive function abilities were measured in this study was within behavioral tasks that are believed to involve executive function. This measure of executive function has been used in prior research with children using cochlear implants; however this research has resulted in contradictory findings. Researchers at the Indiana University have found evidence of poor working memory and attention in children with cochlear implants (Pisoni & Cleary, 2003; Hauser, Lukomski, & Hillman, 2008), and they also used the NEPSY with these children and found they perform more poorly on the Copying and Motor Precision task when compared with hearing children. In contrast, Figureas, Edwards, and Langdon (2008) used the NEPSY and found no differences between the subsets of Tower and Visual Attention of 8-12 year old children with cochlear implants, hearing aids, and normal hearing children. They did however note differences in the number of times the instructed rules were violated during the Tower task, indicating children with cochlear implants may have increased problems with impulse control. This study aimed to clarify these contradictory findings by using a new and larger sample of children with CIs.

In an effort to provide comparable behavioral measures to test the replicability of the prior studies, the current study used the same behavioral measures as indicated above, NEPSY Tower and Visual Attention. To include a measure not related to language ability, the Block Construction task was also used. The current study's results however contradict the findings of Figureas, Edwards, and Langdon (2008). Foremost, the present study identified significant differences between children with CIs and their normal hearing peers' performance on the Tower task and marginally significant differences in the Visual Attention subset, which were not previously documented. In addition, the present study did not find any difference in performance on the Block Construction subset of the NEPSY. Therefore, results indicate that children with cochlear implants do more poorly on tasks measuring nonverbal planning, problem-solving, monitoring, and self-regulation (Tower subset) as well as attention to a visually presented array of pictures (Visual Attention subset).

These differences could be accounted for by a number of variables. Figureas, Edwards, and Langdon (2008) proposed that these EF differences observed in CI children may actually be a result of a language delay rather than executive function impairment. This proposal emerged from a significant positive correlation between their study's overall language ability score and the children's overall executive function performance. Results and analysis of the current study also support this finding. To examine whether this language variable was influencing performance in the current study, language was controlled while running the statistical analyses. This analysis then showed that if language was statistically controlled, no difference in performance between the two measures remained. Due to this diminishing difference between the two groups, it can be concluded that language ability was a significant factor in the initial documented performance difference.

In addition to the above analyses, a correlation was run to investigate the predicted relationship between the two variables. As expected, a significant correlation between how children performed on the PPVT was related to how they performed on the Tower task. A number of reasons may explain why this relationship exists. First, the Tower task requires a heavy language demand in that each child is asked to remember a set of verbally presented instructions through the entire task, and they are corrected each time they forget or make a mistake with these instructions. The task also requires a great deal of language mediation for planning ahead (e.g. red needs to go to blue, but I need yellow to be under blue, etc). Due to CI children's lower language ability as demonstrated on the PPVT, increased difficulty remembering complex instructions while using additional language means to mediate planning decisions is a very realistic prediction. In addition to an increased language demand on the Tower task, the Visual Attention subset also requires a greater demand on language ability. For example, children are asked during the task to find all of the pictures in the array that look like the picture presented. For the children to accurately identify the pictures, children must remember all the features of the picture presented (the man had a mustache, eyelashes, slanted eyebrows etc). Also, the children must remember the directions given, such as to move from left to right looking at all of the pictures within a certain time limitation. Despite the language demands that are required in the Tower and Visual Attention subtests, the Block Construction demands little language use/mediation. Children in this task are given simple, concrete instructions. (e.g. Make your blocks look exactly like this picture.)

Taken together, the results of the current study indicate that children with cochlear implants do perform more poorly on EF measures. To explain these findings, Figueras, Edwards, and Langdon (2008) proposed that their impaired performance may actually be due to their language delay rather than a separate EF impairment. The current study supports this proposal by also finding a significant correlation between these two measures. The analysis completed in both studies however is correlational, and therefore it is possible EF ability actually influences language performance. This proposal however is less possible due to some infants and toddlers having poor EF ability and concurrent normal language acquisition, such as the known population of children with ADHD. Therefore, it seems most probable that children with CIs are performing below their normal hearing peers because they lower language ability is mediating their potential performance.

Parent Report Measures

Three measures of executive function that rely on parental report were also obtained. The behaviors measured by these questionnaires tap a wider variety of activities believed to be influenced by executive function and are apparent in the daily lives of these children.

Behavior Rating Inventory of Executive Function (BRIEF)

The BRIEF is the first parent questionnaire that will be discussed. The BRIEF has begun to be used by a number of researchers investigating executive function abilities, including some work with children with cochlear implants. Much of this preliminary work with children with cochlear implants comes from David Pisoni at Indiana University. He indicated differences in all of the indices of the BRIEF, including the BRI, MI, and GEC. He also found significant differences in the subsets of shifting ability, emotional control, and working memory of the BRIEF. This preliminary work speculated a marked difference in executive function abilities in children who received cochlear implants compared to their normal hearing peers (Pisoni, Conway, Kronenberger, Horn, Karpicke, & Henning, 2008).

However, as above, results of this study contradict previous finding by Pisoni and others. The current study found no significant differences in any of the indices or subsets of the BREIF. This could be due to a number of reasons. First, the present study included a much larger *n* than previous work by Pisoni. Secondly, the population used in this study was taken from the University of Iowa’s Cochlear Implant Research Program. Children with cochlear implants in the state of Iowa largely use total communication as their communication modality. This population may not be representative of all children with CIs, and communication modality has been shown to influence performance with a cochlear implant. Children in the state of Indiana have historically been largely auditory-oral users. Lastly, as in our analysis of the NEPSY, insight into the results can come from an examination of the content of the items on the BRIEF. Unlike the finding that the NEPSY was associated with the PPVT, the BRIEF was not associated with the child's language ability. This suggests that the kinds of behaviors measured on the BRIEF may not require language mediation. Many of the questions on the BRIEF specifically target the desired behavior through questions about ordinary behaviors that occur during the child's day. These are not behaviors that are embedded in a structured task and thus are not behaviors that emphasize strategic planning which lend them verbal mediation. Instead these questions concern behavior regulation. Examples of these questions are such things as "blurt things out" or "lies around the house." In light of this it seems the BRIEF questionnaire may require little/no language mediation and the questions may tap aspects of a number of executive functions without involving a great deal of language. It is also possible that the BRIEF does not measure the EFs that are most relevant and demonstrate differences, as EF entails a number of domains and abilities. Therefore, it may be possible the BRIEF did not target the most relevant or the BRIEF was not sensitive enough to pick up EF differences in children with cochlear implants. Either way it can be determined from these results that children with cochlear implants perform similarly to their normal hearing peers on the BRIEF questionnaire.

Conduct-Hyperactive Attention Oppositional Scale (CHAOS)

Results of the CHAOS parent report questionnaires generally reflect many of the previous findings in both the NEPSY measures and the BRIEF parent report measures. In results of the CHAOS, no difference in performance between the two populations was found on any of the subsets. However, this parent questionnaire is very specific in its executive function targets, and only targets behaviors without language involvement.

This is also demonstrated when a correlation was run looking at a relationship between PPVT scores and overall CHAOS performance. As predicted, this analysis revealed little to no relationship (see Table 8). This questionnaire is designed to measure hyperactivity, oppositional problems, and conduct problems, and includes questions such as “does not finish things that he or she starts,” “is easily distracted by things.” These types of questions, similarly to the BRIEF, address executive function abilities independent of language ability. Due to how this test measures executive function, little to no difference is seen in performance of children with cochlear implants and their normal hearing peers because their performance is not being mediated by their language ability. Results regarding this measure are not consistent with data previously obtained by Pisoni at Indiana University (Pisoni et al, 2008). He found significant differences on attention, hyperactivity, and opposition problems.

Learning, Executive, and Attentional Functioning Scale (LEAF)

The last parent questionnaire to be addressed is the LEAF. This parent questionnaire has also been used previously as a measure of executive function ability in research by Pisoni at Indiana University. His preliminary work suggested that children with cochlear implants performed worse on measures of learning, memory, attention, speed of processing, sequential processing, complex information, and novel problems solving subsets of the LEAF (Pisoni et al, 2008). However, once again the present study does not support a majority of these findings. The present study noted significant difference in the subsets of concept learning, phonological reading, and written subsets, but not in the subsets of attention, speed of processing, sequential processing, complex information processing, and novel problems solving as previously documented by Pisoni.

The reason for the discrepancy in these findings again may be due to a number of factors. First, this measure is designed to asses comprehension and concept learning, factual memory for learning, attention for learning, processing speed, organization and visual-spatial skills, planning and sequential processing, processing of complex information, novel problem-solving, numeric concepts, phonological reading, and written expression. The nature of the abilities that are being examined using this questionnaire are much different than the previous questionnaires in that they often encompass more than one executive function and a number of other domains, including language ability. This can be shown in the area of concept learning for example, which is assessed by questions such as a rating whether or not their child "struggles when learning new material." This sort of rating by the parent may involve the child doing a number of different tasks, which would likely involve learning the new material through both expressive and receptive language means. In addition, when assessing the areas of phonological reading and written abilities, language ability is a likely a strong indicator of performance based on a number of studies documenting a relationship between phonological reading ability, written work, and overall language performance. Therefore, it is likely language would mediate these results in subsets of the LEAF executive function measure.

These relationships are also again demonstrated with correlations that indicate some measures are more highly related to language ability than others. These relationships are again displayed in Table 8. As in other all behavioral and parent report questionnaires discussed thus far, the subsets that noted significant differences (concept learning, phonological reading, and written) between the two populations were also subsets found to have a significant correlation between PPVT scores and executive function performance. Once language was controlled, differences in the population's performance disappeared (see Table 7). This again demonstrates that if language is correlated with PPVT scores in all of the children, children with cochlear implants do significantly worse on the measure.

Conclusions

In conclusion, it seems that performance on parent questionnaires and behavioral measures of executive function are mediated by language ability. Children with cochlear implants did not show any difference in performance compared to their normal hearing peers in areas of executive function that had little/no relationship with PPVT scores (Table A8). When the EF being measured was tightly linked to language ability, children with CIs did significantly worse, and when the language was controlled, no differences were found (Table A7). These results indicate that children with cochlear implants do not have executive function impairments as long as the executive function ability is measured independent of language.

Previous work by Im-Bolter, Johnson, and Pascual-Leone (2006), Figureas, Edwards, Langdon (2008) and Marlowe (2000), support this plausible relationship, as they indicated that a relationship between language ability and executive function ability may exist. Im-Bolter, Johson, and Pascual-Leone (2006) documented significant differences in executive function ability in children with Specific Language Impairment (SLI). These findings indicate that if children differ on their language ability, they will perform significantly worse than their normal developing peers, which supports the claim that language mediates executive performance ability. In addition, Marlowe (2000) believed that this language gap could influence executive function development and performance. He believed that failure to acquire higher level language normally could be a factor in developmental disorders of executive function. This is an important consideration when addressing the tests of interest in this study, since the Tower and Visual Attention subsets require remembering directions, comprehending complex instructions and multi-step directions. It is therefore more likely that children with lower language skills will have more trouble with these subsets because of their poorer language ability. The same is true for measures addressing concept learning, phonological reading, and written work. These tasks are related (as shown in Table A8) and therefore likely influenced more by language. Due to this, parents or caregivers observe their children having increased difficulty in these domains.

Overall, these results indicate that children with cochlear implants perform poorly on some measures of executive function. However, these measures are measures that are highly related to language ability, and it is known that children with cochlear implants often score one standard deviation below their normal hearing peers on these measures. Results of this study indicate that a period of auditory deprivation may potentially cause reorganization as documented in a number of studies including Robinson (1998), Wolff and Thatcher (1990), Kang, Lee, Kang, Lee, Oh, Lee and Kim (2004), and Sharma, Gilley, Dorman, and Baldwin (2007). However, this study suggests that reorganization does not cause system wide deficits which would affect EF ability but rather the affect of the reorganization may be limited to language deficits which may mediate the ability to perform well on tests of executive function.

This belief is also supported in previous research documenting shorter periods of auditory deprivation results in increased language performance (Geers &Moog, 1994; McConkey Robbins, Osberger, Miyamoto, & Kessler, 1995; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000; Blamey, 2001; Bollard, Chute, Popp, & Parisier, 1999; Connor et al., 2000; Miyamoto et al, 1999; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999). However, it should be noted that the current study was unable to find a correlation between these two variables. A lack of significance could be due to a number of factors, including residual hearing at time of implant, bilateral vs unilateral implantation, and communication modality (majority used total communication). Future studies may want to address this unusual and interesting finding.

Together, these results suggest that children do have executive function impairments in areas of measure nonverbal planning, problem-solving, monitoring, and self-regulation abilities (Tower subset) as well as attention to a visually presented array of pictures (Visual Attention subset) which has been documented in previous research.

However, it is likely that these abilities are modulated by children with cochlear implants' poorer language ability as demonstrated on the PPVT, which seems not to be related to their age of implantation.

Behavioral Measures vs Parent Report Measures

In regards to the second aim of the study, both the behavioral measures and the parent report measures identified impairments (subsets that were more related to language ability) adequately. Children with cochlear implants performed more poorly on measures that were significantly related to language ability, whether it is through behavioral measures or parent report measures. This trend was noted in all parent questionnaires and the behavioral measures, and if language ability was controlled, than no difference was found between the two populations (see Table A7 and A8) was noted. Therefore, both the behavioral measures and parent report measures identified impairments in the subsets that required a greater language demand and subsequently subsets that were significantly more difficult for CI children.

Implications and Future Directions

Results of this study support a number of implications and considerations. As described previously, executive function ability is extremely important for daily functioning, learning, and performance in classroom settings. It is shown here that children with cochlear implants do show deficits in a number of abilities such as concept learning, phonological reading, and written work. These deficits were reported by parents, and therefore likely are also noticed by classroom teachers. This study is imperative because it is able to explain that these impairments are not a characteristic of an underlying executive function impairment such as ADHD, but really a characteristic of their likely already identified language delay. This information is vital for both teachers and speech pathologists, because remediation should continue to focus on language. Therefore, this study would support that with improvement in language ability, a number of other areas and performance in the classroom may also improve. These children should therefore not be characterized as impaired in executive function abilities.

Further research should also concentrate on identifying ways of measuring executive function that are not mediated by language. As demonstrated with this study and previous research, children may be misidentified as having an executive function impairment based on measures of executive function that are mediated by language ability. Although no difference was found in identifying impairments related to executive function that may not be mediated by language in this study, behavioral measures were limited. It is proposed that a parent report measure may be easier to design without language as a mediating factor. This is because they are able to measure executive functions without directly testing the child. Testing usually requires verbal instructions, some of which can be complex and place high demands on language abilities.

Additionally, future research should also address reasons for the lack of relationship between age of implant and PPVT scores documented in this study. This finding is not consistent with a large amount of previous research showing a significant relationship between these two variables. This finding may be due to a number of variables such bilateral vs unilateral implantation, residual hearing, and communication modality.

APPENDIX A- TABLES

	CI (n = 33)	NH (n = 29)
% Boys	55%	34%
Age of Participants	*M:* 9 yrs; 9 mons *SD:* 1 yr; 8 mons	*M:* 9 yrs; 6 mons *SD:* 2 yrs
Age Range	6 yrs; 10 mons - 12 yrs; 6 mons	6 yrs; 3 mons- 12 years 4 mons
Age of Implantation	*M:* 2 yrs; 7 mons *SD:* 2 yrs	
Age of Implantation Range	11 mons- 10 yrs; 3 mons	
Length of CI Use	*M:* 7 yrs; 2 mons *SD:* 2 yrs; 2 mons	
Length of CI Use Range	11 mons- 11 yrs	

Table A1. Demographic Information

	CI		NH (n = 29)	
	M	*SD*	*M*	*SD*
Tower *(n = 32)*	8.84	2.9	11.86	2.15
Block Construction *(n = 24)*	10.42	4.04	11.21	2.85
Visual Attention *(n = 25)*	9.44	4.03	11.32	2.75

Table A2. Mean standard scores and standard deviations for the NEPSY subsets

	CI (n = 31)		NH (n = 29)	
	M	*SD*	*M*	*SD*
PPVT SS	78.26	18.84	111.3	12.67

Table A3. Mean standard scores and standard deviations for the PPVT.

	CI (n = 32)		NH (n = 29)	
	M	*SD*	*M*	*SD*
Inhibit-	54.59	9.96	53.34	11.28
Shift- T Score	51.94	10.41	50.14	10.19
Emotional Control	52.34	10.64	50.9	11.84
Initiate	51.41	7.26	50.97	9.79
Working Memory	53.63	9.76	52.83	10.12
Plan/Organize	52.41	7.55	54	8.57
Org. Materials	50.13	9.14	53.24	8.44
Monitor	51.63	11.40	51.41	11.12
BRI	53.53	10.77	51.55	11.14
MI	52.25	7.99	52.97	9.65
GEC	52.88	8.81	52.45	9.81

Table A4. Mean T scores and standard deviations for the BRIEF subsets.

	CI (n = 33)		NH (n = 29)	
	M	*SD*	*M*	*SD*
Concept Learning	5.12	3.04	2.48	2.69
Factual Memory	3.18	3.17	2.69	3.58
Attention	3.45	2.84	4.24	3.30
Processing Speed	4	3.18	3.97	3.31
Organizing Visual Spatial	2.85	2.17	3.76	2.94
Planning Sequential Processing	4.03	2.43	3.79	2.92
Processing Complex Info	4	2.47	3.69	3.12
Novel Problem Solving	3.15	2.91	3	2.85
Numerical Concepts	4.88	3.94	4.69	4.17
Phonological Reading	6.36	4.55	3.28	3.54
Written	5.79	4.37	3.48	3.64
Total	46.82	24.37	39.07	29.54

Table A5. Mean scores and standard deviations for the LEAF.

	CI (n = 33)		NH (n = 29)	
	M	*SD*	*M*	*SD*
Attention Problems	4.36	3.02	5.17	3.33
Hyperactivity	5.03	2.70	4.69	3.50
Opp. Problems	3.55	2.87	3.45	2.71
Conduct Problem	0.61	1.58	0.55	0.83
Total Raw Score	15.79	8.97	16.17	8.15

Table A6. Mean scores and standard deviations for the CHAOS.

Neuropsychological Test	Original p Values	Language Controlled p Values
NEPSY		
Tower	***0.000***	0.265
Visual Attention	***0.052***	0.547
LEAF		
Concept Learning	***0.001***	0.725
Phonological Reading	***0.005***	0.845
Written	***0.033***	0.164

Table A7. P values for t-tests with and without control for performance on the PPVT.

Neuropsychological Test	r =
NEPSY	
Tower	***0.606***
Block Construction	0.203
Visual Attention	***-0.905***
BRIEF	
BRI	-0.119
MI	0.003
GEC	-0.067
CHAOS	
Attention Problems	-0.073
Hyperactivity	-0.277
Oppositon Problem	-0.133
Conduct Problem	-0.172
LEAF	
Concept Learning	***-0.604***
Factual Memory	-0.252
Attention	-0.12
Processing Speed	-0.19
Organizing Visual Spatial	-0.096
Planning Sequential Processing	-0.246
Processing Complex Info	-0.313
Novel Problem Solving	-0.211
Numerical Concepts	0.027
Phonological Reading	***-0.516***
Written	***-0.545***

Table A8. Pearson correlation coefficients for PPVT correlations.

APPENDIX B- FIGURES

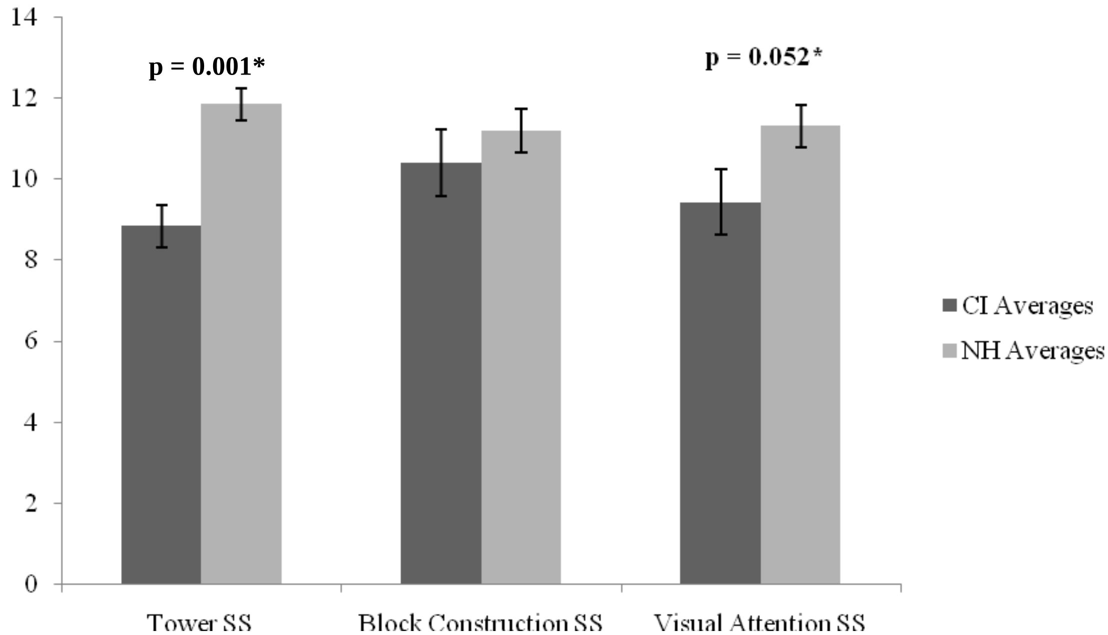

Figure B1. Means of the standard scores of the three NEPSY measures.

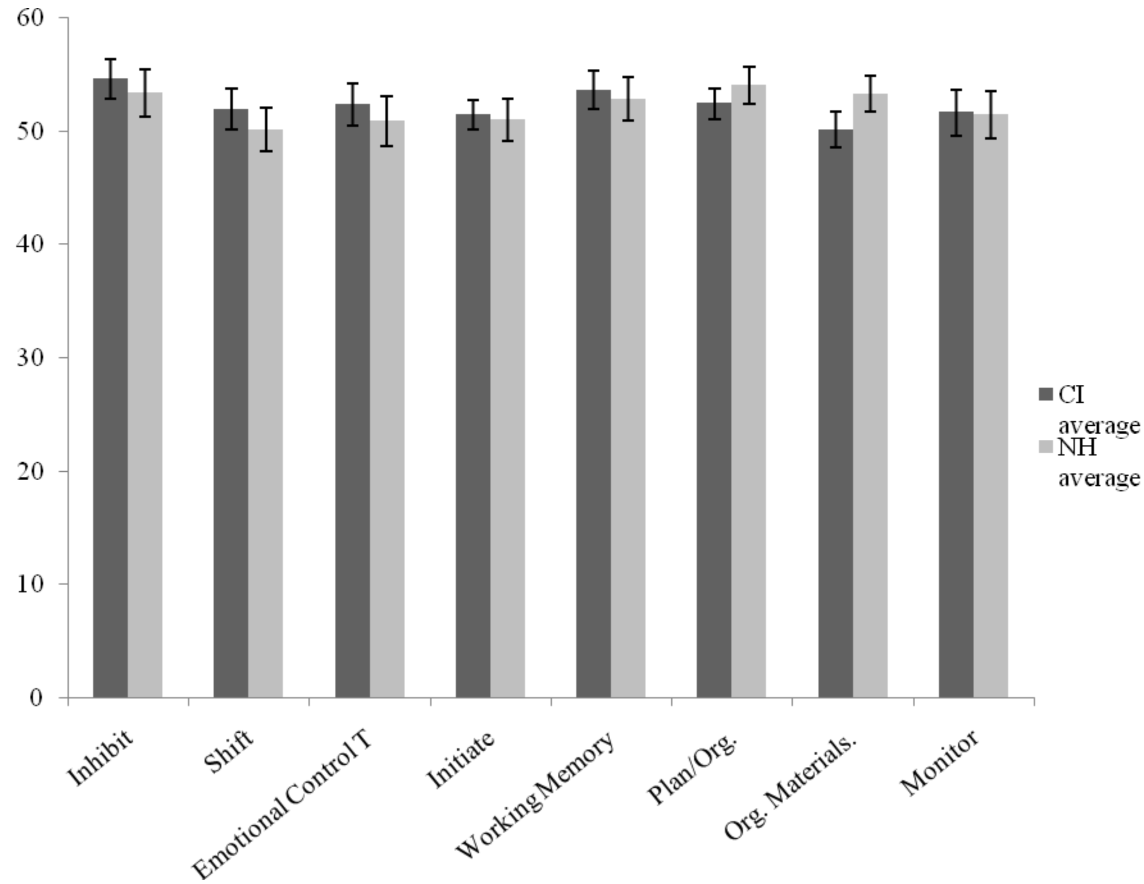

Figure B2. Mean T Scores for each BRIEF subset.

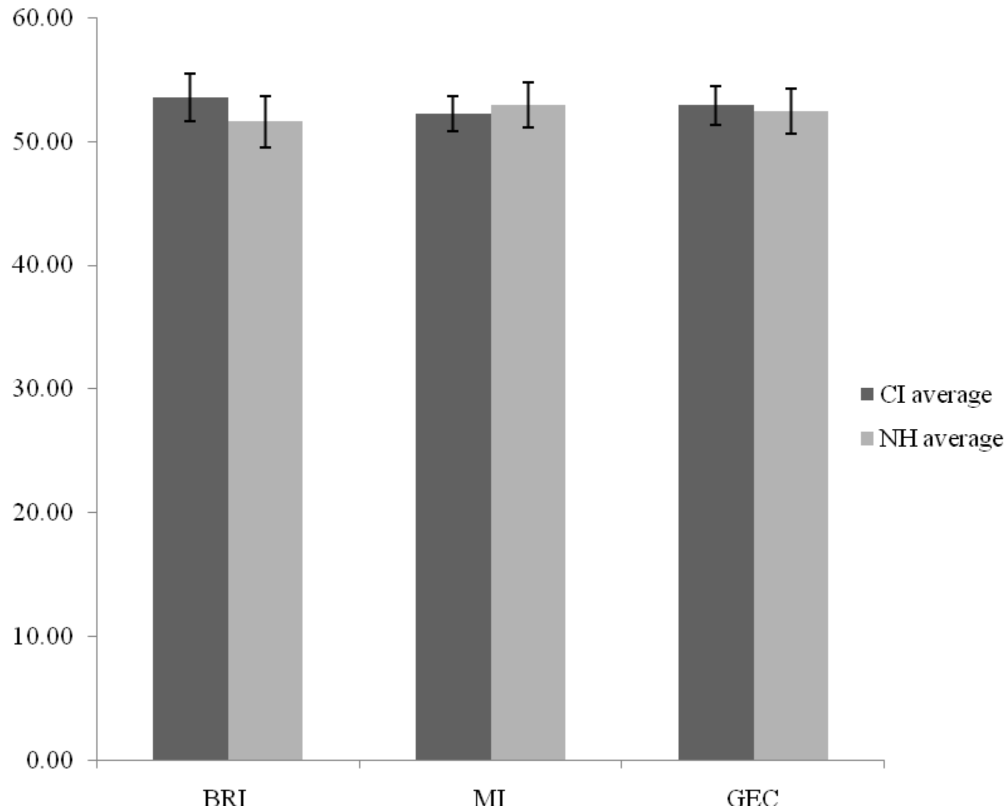

Figure B3. Mean T scores for the three BRIEF indexes.

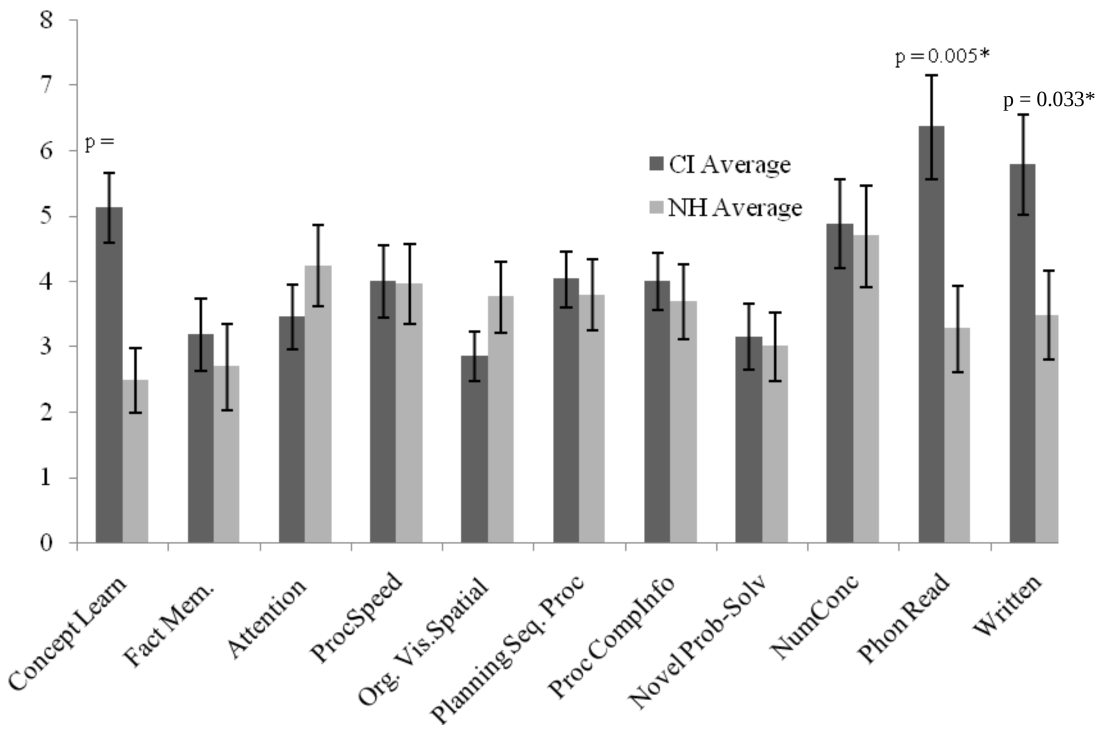

Figure B4. Mean scores of LEAF subsets.

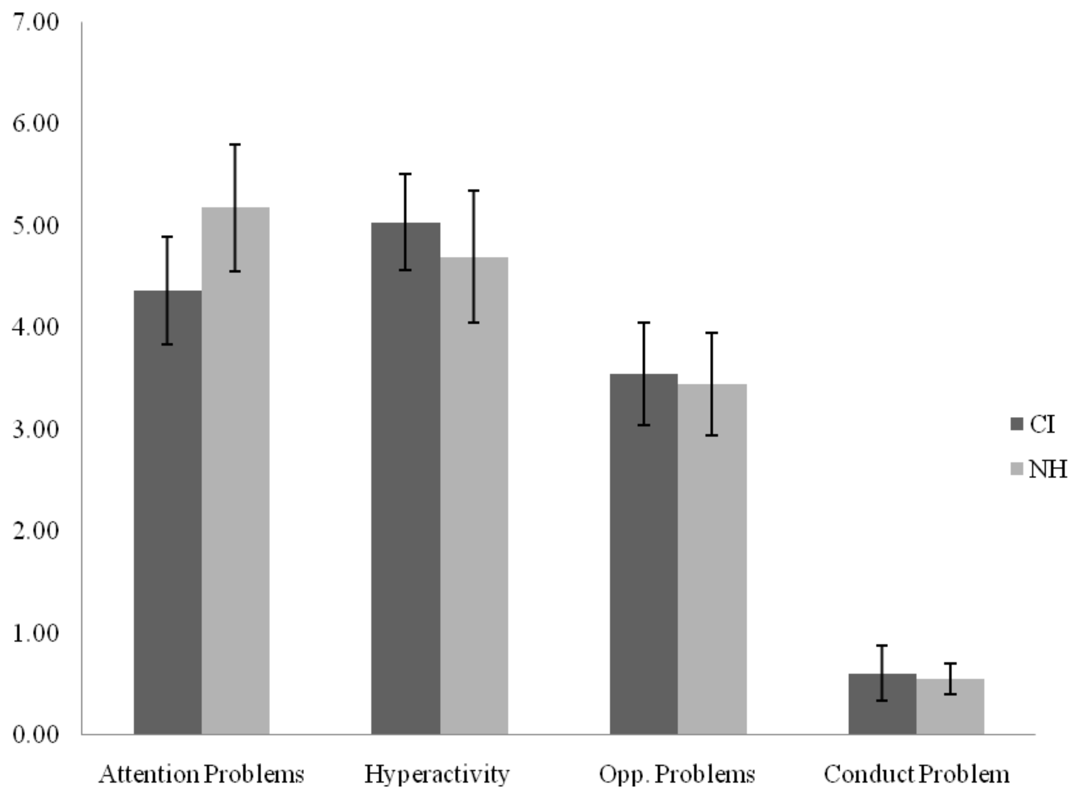

Figure B5. Mean scores of CHAOS subsets.

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