Purpose: In the present study, the authors examined lexical naming in children with cochlear implants (CIs). The goal was to determine whether children with CIs have deficits in lexical access and organization as revealed through reaction time in picture-naming and verbal fluency (VF) experiments.

Method: Children with CIs (n = 20, ages 7–10) were compared with 20 children with normal hearing (NH) matched for age and nonverbal IQ. Lexical abilities were examined using two naming tasks: a timed picture-naming task and a phonological and semantic VF naming task. Picture naming taps into lexical access capabilities and the VF task elucidates lexical organization.

Results: No group differences were found between children with CIs and children with NH on the timed picture-naming task. Children with CIs generated significantly fewer words than the children with NH on the VF tasks. Larger group differences were found for the phonological VF task compared with the semantic VF task.

Conclusions: Limited early linguistic and auditory experiences may affect lexical representations and organization (lexical-semantic connections) in school-age children with hearing loss who use CIs. Further analyses and studies should continue to examine these underlying linguistic deficits. The present results suggest a need to emphasize not only increasing the size of children’s vocabularies during therapy, but also expanding and increasing the semantic and phonological richness of their lexical representations.

Key Words: cochlear implants, language, naming, lexical access, lexical representations, lexical organization, children

Although some children with cochlear implants (CIs) acquire oral language with similar success and at a similar rate compared with their hearing peers, many others do not achieve age-appropriate language skills (e.g., Blamey et al., 2001; Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Geers, Nicholas, & Sedey, 2003; Nikolopoulos, Dyar, Archbold, & O’Donoghue, 2004; Niparko et al., 2010). Previous studies have provided important information about the general effectiveness of implantation but have not fully explained the considerable variability still present in language outcomes. Efforts continue toward identifying specific aspects of language processing which may be vulnerable in this clinical population, especially isolated deficits for which remediation might be feasible.

A number of studies have focused on specific areas of language, such as phonology (Chin & Pisoni, 2000; Serry & Blamey, 1999), inflectional morphology (Spencer, Tye-Murray, & Tomblin, 1998; Szagun, 2004), vocabulary and the lexicon (Fagan & Pisoni, 2010; Schwartz, Steinman, Ying, Ying Mystal, & Houston, 2013), semantics (Le Normand, Ouellet, & Cohen, 2001), and grammar (Nikolopoulos et al., 2004). Some of these studies have generally suggested that storage and retrieval of language-based information from lexical (long-term) memory may be an issue in some subset of this clinical population (Schwartz et al., 2013). In the present study, we use measures not previously used with this population to investigate this possible underlying cause for language delays in some children with CIs. Articulating verbal labels for concepts, or naming, is arguably the fundamental basis for early language formulation. It is, therefore, essential to examine lexical naming abilities in the pediatric CI population.

Picture Naming as an Indicator of Language Deficits

Naming is a common means of evaluating language progress and deficits and a hallmark of specific language...
impairments (Leonard, 2000; Leonard, Nippold, Kail, & Hale, 1983). Picture naming has been used to examine lexical access in adults (D’Amico, Devescovi, & Bates, 2001; Jescheniak & Levelt, 1994) as well as in children with both typical and atypical development (Leonard et al., 1983; Miller, Kail, Leonard, & Tomblin, 2001; Seiger-Gardner & Schwartz, 2009). The timed picture-naming task yields accuracy and reaction time (RT) measures. In children with typical development, performance on naming tasks improves with age (more accurate and faster RTs). This improvement has been attributed to maturational changes in processing rate (Kail, 1991). Slower processing speed has been assumed to reflect limitations in processing capacity and resources, including less rapid access to object names (Cook & Meyer, 2008; Miller et al., 2001).

Picture naming involves a series of stages. These stages include object recognition, lexical retrieval, formulation, and production (Miller et al., 2001; Nation, Marshall, & Snowling, 2001). Deficits in any of these processes may result in slower picture naming. Although global RT measures provide limited information regarding specific stages in the naming process, they do provide useful information about normal maturation and about lexical production in children with atypical development (D’Amico et al., 2001; Nation et al., 2001).

RT during picture naming is influenced by characteristics of the individual word (e.g., word length, frequency, familiarity, age of acquisition, phonological features) (e.g., D’Amico et al., 2001; Jescheniak & Levelt, 1994). Early acquired words are retrieved faster and more accurately than later acquired words. Longer names require more phonological information to be specified in and retrieved from long-term memory. Thus, naming tends to be slower and less accurate as word length increases (Cycowicz, Friedman, Rothstein, & Snodgrass, 1997; Nation et al., 2001).

Word familiarity and word frequency also influence lexical access (Almeida, Knobel, Finkbeiner, & Caramazza, 2007; Jescheniak & Levelt, 1994; Schwartz, 1995). Word familiarity affects word duration in adult and child speech. Schwartz (1995) reported an effect of familiarity on the duration of vowels and words produced by young children. The duration of children’s productions decreased with increasing familiarity. Subjects are also typically faster (Almeida et al., 2007) and more accurate (Newman & German, 2005) naming pictures that have highly familiar or frequent names. The common view holds that these frequency–familiarity effects arise as a result of differences in representation or processing of high and low frequency lexical representations (Almeida et al., 2007). High familiarity words are thought to have stronger semantic representations because they consist of a greater number of attributes or features (Nation et al., 2001). In addition, word frequency has been shown to serve as a strong predictive variable across languages, and this effect may reflect the link between word meaning and word form—that is, connections between semantic and phonological representations (Bates et al., 2003). Thus, the timed picture-naming task appears to be sensitive to universal processes that are not detected using off-line (non-timed) naming measures. Identifying word-naming deficits in individuals is important, since these deficits can often be improved via therapy (Best, 2005; Bragard, Schelstraete, Snyers, & James, 2012).

**Verbal Fluency as an Indicator of Language Organization**

Verbal fluency (VF) tasks have been used to examine lexical organization in adults and children with typical and atypical language abilities (Sauzéon, Lestage, Raboutet, N’Kaoua, & Claverie, 2004; Troyer, 2000; Winkerly, Wulfbeck, & Reilly, 2001). In this task, the subject is given a category (e.g., semantic—food; phonological—f as an initial sound) and asked to name as many words as possible in that category within a specified time period. The number of words produced for phonological and semantic tasks are compared across groups.

Optimal performance in a VF task involves generating words within a subcategory and, when a subcategory is exhausted, switching to a new subcategory. According to Troyer, Muscovitch and Winocur (1997), two dissociable components underlie VF performance: clustering and switching. A cluster is a sequence of semantically or phonetically related words. A semantic cluster in the category animals, for example, could include a sequence of words from the subcategory of pets, such as cat, dog, fish. A phonological cluster is a sequence of words that share similar phonemes, such as fat, feet, foot, fit. Successful performance on the VF task requires a balance between clustering and switching abilities, which reflect the underlying organization of the lexicon and access to the lexicon. Thus, the VF tasks reveal important information about the underlying representation and organization of words in memory.

A number of studies have revealed developmental changes in VF performance from 5 to 16 years (Riva, Nichelli, & Devoti, 2000; Sauzéon et al., 2004). Children in the older age groups showed an increase in the number of items retrieved (Kail & Nippold, 1984). Although children improved with age on both semantic and phonological tasks, young children performed relatively better on semantic tasks, whereas phonological improvements were more gradual (Riva et al., 2000; Sauzéon et al., 2004). The differences in performance on these two tasks (phonological and semantic) may be related to the hierarchical organization of the phonological and semantic information in the subject’s mental lexicon. Research in the area of semantic categorization has pointed out that words and concepts are internally structured (Mervis & Rosch, 1981). Any object may be categorized at each of several different hierarchical levels: subordinate (e.g., animal), basic (e.g., bird), and subordinate (e.g., canary) levels. The basic level is the most general level. Basic level categories are acquired before categories at other hierarchical levels (Rogers & Patterson, 2007).

Developmental changes were also described for clustering and switching abilities in the VF semantic and phonological tasks. Children in fifth grade (ages 10–11 years) had larger semantic and phonological fluency scores than...
children in the third grade (ages 8–9 years), concomitant with an increase in the number of clusters but not in cluster size (Koren, Kofman, & Berger, 2005; Sauzéon et al., 2004). Examining these specific factors in VF performance has the potential to advance our knowledge regarding the organization of the lexicon that underlies word retrieval abilities and to help to direct therapy. In cases where VF difficulty is present, therapy should focus on strengthening the connections between words and the organization of the lexicon, either at the phonological level, at the semantic level, or by strengthening lexical-semantic connections.

In summary, the tasks we have applied, timed picture naming and VF naming, provide information about lexical retrieval and lexical organization that may underlie the language deficits observed in some children with CIs. These methods were used to further explore phonological and semantic factors in lexical access for production. In the picture-naming task, we examined word length and familiarity effects, and in the VF task, we examined word initial consonant and semantic categories. We hypothesized that children with CIs would show overall slower RTs and particularly slow responses for less familiar and longer words as a result of reduced linguistic experience and subsequently less well developed lexical representations. Similarly, we hypothesized that children with CIs would name fewer words on both semantic and phonological VF tasks due to less rich connections between lexical representations of words and their attributes. We expected the phonological VF task to be more difficult as compared with the semantic VF task, given a greater likelihood of impoverished phonological representations as compared with conceptual representations in the CI group. Specifically, we expected fewer clusters and switches due to differences in the organization of the lexicon based on phonological features. In addition, because age at implantation and amount of CI experience are variables that are known to affect language outcome (e.g., Geers & Nicholas, 2013; Holt & Svirsky, 2008), the relationship among these variables and naming was examined. We expected earlier implantation and longer CI experience to be correlated with better naming performance. Finally, we assessed whether naming skills could be predicted by performance on a brief general language screening measure. We hypothesized that children with CIs who have language scores within the normal range for their age might show relatively better naming.

### Experiment 1: Timed Picture Naming

**Method**

**Participants**

Forty subjects (20 CI and 20 with normal hearing [NH]) ages 7–10 years were included in the final analysis of the present study. These subjects were chosen from a slightly larger group of children who participated. Three participating children with CIs (from the larger group) were excluded because of poor speech intelligibility, which did not permit accurate scoring of their responses. One additional child with a CI was excluded from the analysis because of attention-deficit/hyperactivity disorder (he was receiving medication; he did not complete all of the tasks). Each child from the CI group was matched with a child with NH according to age and nonverbal IQ (Test of Nonverbal Intelligence [TONI–3]; Brown, Sherbenou, & Johnson, 1997). The children were matched within 4 months of age and 5 points on the TONI–3 standardized score. This matching procedure yielded a total of 40 subjects, 20 CI and NH pairs, who were included in the final analysis for both experiments.

All participants underwent language screening (but not a full language assessment, due to time limitations). The Clinical Evaluation of Language Fundamentals, Third Edition screening test (CELF–3; Semel, Wiig, & Secord, 1995) was used. In addition, TONI–3 was administered to NH and CI subjects. Only children with NH who passed a hearing screening (described below) and the CELF–3 language screening, with IQs above 80 on TONI–3, were included in the study. The participants’ demographic and socioeconomic status characteristics (e.g., parents’ highest education level) matched the distribution of the population in the greater New York City area. English was the primary language of all children tested.

The criteria for CI participants were severe to profound bilateral sensorineural hearing loss diagnosed before the age of 3 years, with at least 7 months of experience with CI prior to participation in this study. All the children in the CI group were users of oral communication or total communication. Children who primarily used sign (manual) language were excluded because they would not be able to perform the verbal naming tasks. The children with CIs were asked to use the typical settings for their CI(s) and hearing aid. The examiner confirmed with the children and their parents that the hearing devices were working properly.

The criteria for hearing participants were as follows: no parentally reported history of speech or language deficits, no reported neurological or emotional disorders, and no known visual impairments that cannot be corrected by glasses. All children with NH underwent an audiological screening before initiating the actual experiments. This was conducted in the experiment room, which was a quiet testing room. The passing criterion was 20 dB HL at audiometric frequencies between and including 500 to 4000 Hz. Two responses were required at each frequency in each ear in order to pass the hearing screening. Only children with NH who passed the hearing screening were included in the final analysis.

**Participants with NH.** Twenty children with NH (ages 7;0–10;0 [years;months], M = 8;7, SD = 1.12) were included. Fourteen were girls and six were boys. The average TONI–3 score was 109.3, SD = 10.2.

**Participants with CI.** Twenty children with CIs (ages 7;0–10;2, M = 8;7, SD = 1.11) were included. Nine were girls and 11 were boys. The average TONI–3 score was 109.7, SD = 11.5. All children with CIs had severe to profound bilateral sensorineural hearing loss diagnosed before the age of 3 years, with at least 7 months of experience with CI prior to participation in this study. All the children in the CI group were users of oral communication or total communication. Children who primarily used sign (manual) language were excluded because they would not be able to perform the verbal naming tasks. The children with CIs were asked to use the typical settings for their CI(s) and hearing aid. The examiner confirmed with the children and their parents that the hearing devices were working properly.
profound prelingual sensorineural hearing loss and were using Nucleus CI devices. They were all performing well with their implants. Average pure-tone average (PTA) in the implanted ear was 21.19 dB (range 11.6–33.3). All participants were enrolled in a mainstream school setting. Characteristics of the participants with CI are provided in Table 1. Some of the children were missing preimplant PTAs because they were implanted at a different center; however, all postimplant PTAs are included in the table. Ten children in the group had language scores at or above age level and nine others failed the CELF.

A practice session, with four practice words (bed, car, envelope, glasses), that were not included in the experimental analysis, preceded the actual experiment. The instructions were as follows: You are going to see pictures on the screen. I want you to tell me what each picture is as fast as you can. If necessary, the experimenter corrected the child’s performance during this practice procedure (e.g., Don’t use a/an before saying the word). After the practice session, the actual experiment began. Each picture appeared on the screen until the voice key detected a verbal response and then disappeared. Once the picture had disappeared, a fixation point (+) appeared on the computer screen for 2000 ms, followed by the next picture. The child had 4 s to produce the word. If no response was detected after a period of 4 s, the next picture was presented. The investigator noted the child’s verbal response and any interruptions (e.g., saying ah, coughing). In addition, the sessions were audio recorded and digitized for scoring purposes. The child’s responses were transcribed and scored.

Scoring

Each response was scored for accuracy. Mispronunciations or misarticulations were included as correct responses as long as the misarticulated phoneme was pronounced consistently by the child and as long as the target word was intelligible. Measurements of RT were collected by E-Prime for each correct response. Because the goal was to compare RTs for the same retrieved words (that include the same phonemes) across both groups, only correct responses of the intended picture were included in the RT measurements. If the child named a picture correctly but used a synonym word, or added an extra word (e.g., wishing well for well), the child received a point for the accuracy, but the RT was not included in the analysis because of the extra word. Similarly, only the naming of the intended words was scored as correct. If the child said duck for swan, the word duck was scored as incorrect. False triggers (interrupting sounds or movements, e.g., cough or body movements that intervened in the RT measurement) and incorrect responses (e.g., duck instead of swan; bird instead of penguin) were excluded from the final RT measurement. Responses that were measured by E-Prime as less than 400 ms were removed (only 10 instances in the CI group and 11 instances in the NH group; 2.0% and 2.2% of the data, respectively).

Interjudge reliability. A second experimenter listened to a randomly selected 20% of the recordings. The experimenter transcribed the responses and provided an accuracy score. Each response was scored as correct or incorrect. Mispronunciations and misarticulations were included as
### Table 1. Characteristics of the children in the cochlear implant group.

<table>
<thead>
<tr>
<th>CI Participant</th>
<th>Age at activation</th>
<th>Etiology of HL</th>
<th>Age at HL onset</th>
<th>Age HL identified</th>
<th>Unaided PTA</th>
<th>Post PTA</th>
<th>CI duration</th>
<th>CI</th>
<th>Hearing device</th>
<th>Nucleus processor</th>
<th>SP scheme</th>
<th>CELF–3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4:5</td>
<td>EVA</td>
<td>5 months</td>
<td>1;4</td>
<td>73.3</td>
<td>81.6</td>
<td>28.3</td>
<td>5:6</td>
<td>CI</td>
<td>None</td>
<td>ESPrIt</td>
<td>ACE</td>
</tr>
<tr>
<td>2</td>
<td>3:7</td>
<td>Genetic</td>
<td>Birth</td>
<td>1;7</td>
<td>NI</td>
<td>NI</td>
<td>23.3</td>
<td>5:6</td>
<td>CI</td>
<td>HA</td>
<td>ESPrIt</td>
<td>ACE</td>
</tr>
<tr>
<td>3</td>
<td>5:0</td>
<td>Unknown (&lt;1;0)</td>
<td>Birth</td>
<td>1;0</td>
<td>95</td>
<td>93.3</td>
<td>25</td>
<td>2:5</td>
<td>CI</td>
<td>CI (1st)</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>4</td>
<td>5:9</td>
<td>Genetic (Cx26)</td>
<td>Birth</td>
<td>1:6</td>
<td>100</td>
<td>85</td>
<td>21.6</td>
<td>2:2</td>
<td>CI</td>
<td>HA</td>
<td>SPrint</td>
<td>ACE</td>
</tr>
<tr>
<td>5</td>
<td>7:0</td>
<td>Genetic</td>
<td>Birth</td>
<td>1:6</td>
<td>NI</td>
<td>NI</td>
<td>NI</td>
<td>1:0</td>
<td>CI</td>
<td>HA</td>
<td>NI</td>
<td>f</td>
</tr>
<tr>
<td>6</td>
<td>7:2</td>
<td>Unknown</td>
<td>Unknown</td>
<td>3:0</td>
<td>83.3</td>
<td>76.6</td>
<td>23.3</td>
<td>1:9</td>
<td>CI</td>
<td>HA</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>7</td>
<td>7:1</td>
<td>Genetic</td>
<td>Birth</td>
<td>NI</td>
<td>85</td>
<td>&lt;120</td>
<td>23.3</td>
<td>0:7</td>
<td>CI</td>
<td>None</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>8</td>
<td>1:11</td>
<td>Unknown</td>
<td>Birth</td>
<td>Birth</td>
<td>111.6</td>
<td>108.3</td>
<td>28.3</td>
<td>5:0</td>
<td>CI</td>
<td>HA</td>
<td>ESPrIt</td>
<td>ACE</td>
</tr>
<tr>
<td>9</td>
<td>1:10</td>
<td>Wardenburg Syndrome</td>
<td>Birth</td>
<td>Birth</td>
<td>NI</td>
<td>NI</td>
<td>18.3</td>
<td>8:0</td>
<td>None</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>10</td>
<td>2:9</td>
<td>Genetic (Cx26)</td>
<td>Birth</td>
<td>Birth</td>
<td>NI</td>
<td>&gt;120</td>
<td>33.3</td>
<td>7:4</td>
<td>CI</td>
<td>None</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>11</td>
<td>1:5</td>
<td>Genetic (Cx26)</td>
<td>Birth</td>
<td>1:4</td>
<td>110</td>
<td>111.6</td>
<td>20</td>
<td>6:2</td>
<td>CI (1st)</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>12</td>
<td>1:11</td>
<td>Unknown</td>
<td>Unknown</td>
<td>1:0</td>
<td>NI</td>
<td>NI</td>
<td>18.3</td>
<td>7:10</td>
<td>None</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>13</td>
<td>2:5</td>
<td>Long QT</td>
<td>Birth</td>
<td>8 months</td>
<td>NI</td>
<td>NI</td>
<td>16.6</td>
<td>6:11</td>
<td>CI</td>
<td>None</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>14</td>
<td>1:1</td>
<td>Genetic</td>
<td>Birth</td>
<td>NI</td>
<td>111.6</td>
<td>113.3</td>
<td>21.6</td>
<td>8:2</td>
<td>CI (1st)</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>15</td>
<td>1:1</td>
<td>Genetic (Cx26)</td>
<td>Birth</td>
<td>Birth</td>
<td>NI</td>
<td>NI</td>
<td>13.3</td>
<td>9:1</td>
<td>None</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>16</td>
<td>2:10</td>
<td>Genetic (Cx26)</td>
<td>Birth</td>
<td>1:7</td>
<td>91.6</td>
<td>86.6</td>
<td>21.6</td>
<td>4:5</td>
<td>CI (1st)</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>17</td>
<td>3:3</td>
<td>Unknown</td>
<td>Birth</td>
<td>Birth</td>
<td>103.3</td>
<td>105</td>
<td>16.6</td>
<td>4:0</td>
<td>CI (1st)</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>18</td>
<td>2:8</td>
<td>Premature</td>
<td>Unknown -passed Antibiotics</td>
<td>6 months</td>
<td>NI</td>
<td>88.3</td>
<td>20</td>
<td>4:4</td>
<td>CI (1st)</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
</tr>
<tr>
<td>19</td>
<td>1:6</td>
<td>Unknown</td>
<td>Antibiotics 11 months</td>
<td>103.3</td>
<td>106.6</td>
<td>11.6</td>
<td>6:7</td>
<td>CI</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>3:5</td>
<td>Unknown</td>
<td>Antibiotics 11 months</td>
<td>103.3</td>
<td>106.6</td>
<td>11.6</td>
<td>6:7</td>
<td>CI</td>
<td>CI</td>
<td>Freedom</td>
<td>ACE</td>
<td></td>
</tr>
</tbody>
</table>

**Note.** Age and CI duration are provided in years;months, pure-tone average (PTA) in dB. HL = hearing loss; post PTA= postimplant PTA; CI = cochlear implant; HA = hearing aid; SP = speech processing; EVA = enlarged vestibular aqueduct; Cx26 = Connexin 26; CMV = cytomegalovirus; NI = no information available; CELF–3 = Clinical Evaluation of Language Fundamentals screening test (Semel, Wlg, & Secord, 1995); p = pass, f = fail.
a correct response as noted above. Interjudge reliability, calculated with Pearson product–moment correlation coefficients, was 99% for the accuracy score.

Results

General Analyses: Description of the Analyses Performed

Linear mixed-model analyses of variance (ANOVAs) with repeated measures were used. Prior to analysis, the data error variance–covariance matrix was examined to test for the error structure that best fitted the data. The variance–covariance structure that fitted the data best was the unstructured matrix. Tukey’s honestly significant difference test (Hinton, 2004) was used for post-hoc comparisons. For all analyses, alpha levels were set at .05.

RT was the primary dependent measure, with group serving as a between-subject variable and familiarity and word length serving as within-subject variables. Correlations between background factors in the CI group (age, TONI–3 nonverbal IQ, age at implantation, total time of experience with the CI device, and language scores) and RTs in the picture-naming task were also examined.

Main Effect

Accuracy (percent correct). In most cases, members of both groups of participants, CI and NH, named the intended word. The average number of correct responses in the NH group was 20.9 out of 24 pictures presented (87.2% correct, SE = 0.35) and the average number of correct responses in children with CIs was similar, 19.6 (81.6% correct, SE = 0.61). The difference between the groups was not statistically significant, t(1, 39) = 1.9, p > .05, d = 0.61.

RT. Mean RT (in milliseconds) for correct responses on the timed picture-naming task for the CI group was 956 ms (SE = 34.5), and for the NH group, 919 ms (SE = 34.6). Although the observed pattern of RT means was in the predicted direction (i.e., CI slower than NH), the difference between groups in overall naming time was not statistically reliable, F(1, 38) = 0.88, p > .05, d = 0.23.

Length and familiarity effects. Length and familiarity effects were also examined. Average RTs for each group, grouped by word characteristics (word length and familiarity) of the pictures to be named are displayed in Table 2. High familiarity words yielded faster RTs than low familiarity words, F(1, 38) = 45.13, p < .001, d = −1.76.

Table 2. Mean reaction time in milliseconds for the picture-naming task grouped by familiarity levels and by word length; standard errors in parentheses.

<table>
<thead>
<tr>
<th>Group</th>
<th>High familiarity</th>
<th>Low familiarity</th>
<th>Short words</th>
<th>Long words</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>843 (39.4)</td>
<td>1070 (44.9)</td>
<td>896 (34.4)</td>
<td>1016 (42.4)</td>
</tr>
<tr>
<td>NH</td>
<td>790 (39.4)</td>
<td>1048 (45.2)</td>
<td>917 (34.4)</td>
<td>921 (42.6)</td>
</tr>
<tr>
<td>Overall</td>
<td>817 (27.9)</td>
<td>1059 (33.1)</td>
<td>907 (24.4)</td>
<td>969 (31.6)</td>
</tr>
</tbody>
</table>

Short (monosyllabic) words yielded faster RTs than long (bisyllabic) words, F(1, 38) = 5.26, p < .05, d = −2.19. The interaction between group and familiarity was not statistically significant, F(1, 38) = 0.22, p > .05, d = 0.07. In both groups, the same pattern was found: highly familiar words were faster to be named than less familiar words. However, the interaction between group and word length was found to be statistically significant, F(1, 38) = 7.27, p = .01, d = 2.36. For the NH group, no difference was found in retrieval time for monosyllabic versus bisyllabic words, but the children with CIs were slower to name longer words. In addition, there was a statistically significant interaction between familiarity and word length across all subjects, F(1, 38) = 7.48, p < .01, d = 2.43. Overall, across all subjects, highly familiar words, regardless of their length (short or long), were named at similar RTs. In contrast, for less familiar words, there was a length effect. Long words of low familiarity were significantly slower to be named than short words of low familiarity.

Correlations With Background Factors in the CI Group

Pearson product–moment correlation coefficients were computed between background factors in the CI group (age, TONI–3 nonverbal IQ, age at implantation, total time of experience with the CI device, language screening results) and RTs in the picture-naming task. The results of these correlations are reported in Table 3. Nonverbal IQ scores were correlated with performance on short highly familiar words and with performance on the long less-familiar words of the picture-naming task (i.e., higher nonverbal scores were associated with shorter RTs in these conditions). In addition, age at implantation and years of CI use were correlated with performance on long highly familiar words of the picture-naming task. In this condition, older age at implantation was associated with longer RT, and more years of CI use was associated with shorter RT. Language levels were not reliably correlated with any of the RT measures, but the correlations fell in the predicted direction for all but one condition examined.

Discussion

We hypothesized that children with CIs would show deficits in retrieval during naming due to limitations in lexical representation as a result of their atypical and reduced experience with spoken language. However, the results of Experiment 1 did not support this hypothesis. Overall naming times for children with CIs were similar to those of their NH peers, as was the familiarity effect. These results imply that children with CIs are sensitive to the frequency and semantic underpinnings of words, the primary components of familiarity. These data are surprising but encouraging because they demonstrate that the retrieval mechanism of children with CIs seems to be similar to that of children with NH, and that the source of their language deficit is likely to differ from that of other clinical populations, such as children with specific language impairment.
However, we found an interaction of Group × Word Length. For the NH group, no word length effect was observed; no significant difference was found in RTs for monosyllabic versus bisyllabic words. In contrast, the children in the CI group were slower by 120 ms to name bisyllabic words than monosyllabic words. We assume that the NH group did not exhibit the typically observed length effect due to this study involving relatively short words, varying in length by only one syllable, which were not sufficiently challenging for the NH participants. In contrast, the CI group did show a length effect, and the introduction of just one syllable to the word to be named significantly slowed down the retrieval times. This difference may imply that the lexicon of children with CIs is more susceptible to even small phonological challenges. Follow-up experiments should examine a larger number of stimuli that include longer (three syllables and more) and less-familiar words in order to identify the source of this finding.

### Experiment 2: VF Naming Tasks

#### Method

**Participants**

The same 40 children—20 matched CI and NH pairs—who took part in Experiment 1 participated in the phonological and semantic VF tasks for Experiment 2. (See the Participants section of Experiment 1 for a full description.)

**Stimuli and Procedure**

In the VF task, children were given 1 min to generate as many words as possible beginning with a particular speech sound or from a specific semantic category. In the VF phonological task, the child was asked to say as many words as possible that begin with a given sound (/t/, /l/, /f/) within 1 min. The three phonological subtasks (/t/, /l/, and /f/) were presented in this order. These particular sounds have been used commonly in the literature (e.g., Riva et al., 2000; Troyer, 2000). Also, these sounds represent a diverse range of speech sound characteristics. These sounds include both voiced and voiceless consonants (/l/ = voiced; /l/ and /f/ = voiceless). The three phonemes chosen also represent different places of articulation (/t/ and /l/ = coronal; /l/ = labiodental) and different manners of articulation (/l/ = plosive; /l/ = lateral; and /f/ = fricative). The instructions were: *I will tell you a sound, and then I want you to say in one minute, as many words as you can that begin with that sound.*

In the semantic VF task, the child was asked to name as many words as possible that belong to a given semantic category (*animals, foods*) in this order. These categories were chosen because they have been used extensively in previous research, and because they are highly familiar categories.

The sound /m/ was given as an example for the phonological tasks. The experimenter named possible words (*map, movie, morning*) and then asked the child to say more words that begin with /m/. The category clothing was given as an example for the semantic task. The experimenter demonstrated that the child could say *shirt, socks, shoes,* and asked the child to say more words that belong to the clothing category. The child began when the experimenter said *go.* This session was also audio recorded and digitized for scoring purposes. The investigator transcribed the children’s responses.

#### Scoring

A separate score for each of the five subtasks was obtained. Each correct word received one point. In addition, a total score for the phonological VF task and a separate total score for the semantic VF task were calculated. The total score was the average across the phonological and semantic categories for each task (Koren et al., 2005; Troyer, 2000; Troyer, Muscovitch, & Winocur, 1997). Repetitions, errors, and unintelligible words were not included in the final score.

Additional detailed clustering and switching analyses of the subjects’ responses in the VF tasks were conducted. The rules for defining and scoring clusters were based on Koren et al. (2005), Troyer (2000), and Troyer et al. (1997). The analysis included both semantic and phonological clusters. Semantic clusters consist of words with related meanings that belong to the same subcategory (e.g., sea animals: *seal, dolphin, whale, fish* or jungle animals: *lion, giraffe, monkey*) according to lists of common subcategories of animals and food listed in Koren et al. (2005), Troyer (2000), and Troyer et al. (1997). Phonological clusters consist of words that share similar phonemes, according to the
following criteria: words that begin with two consecutive identical phonemes (e.g., /fr/ fright, fraud, free, fry), words that rhyme, or phonological neighbors (e.g., /f/ fat, feet, foot, fit). Groups of two or more successively produced words, belonging to the same semantic or phonological subcategory, were counted as a cluster.

The analyses also included the number of switches within each subject’s response. Switches were defined as transitions from one word, or a group of words (cluster) to the next word (or cluster). Repetitions were included in the cluster and switch analysis. The mean cluster size (MCS) measure was calculated by averaging the cluster size scores across each task. For each of the measures, a separate score was calculated for the phonological task, and a separate score was calculated for the semantic task.

Results

General Analyses: Description of the Analyses Performed

Separate linear mixed-model ANOVAs with repeated measures for each task (phonological and semantic) were conducted. The data error variance–covariance matrix was examined to test for the error structure that best fit the data. The ANOVA was conducted accordingly. For the total number of words measure, the error structure that fit the data best was unstructured for both phonological and semantic total number of words scores.

The dependent measures were the number of words. CI and NH groups were the between-subject variables and the tasks (each phonological or semantic category) were the within-subject variables. Correlations among variables of interest (such as age, TONI-3 nonverbal IQ, age at implantation, total time of experience with the CI device, language scores) and performance on the VF naming task were also performed. Linear mixed-model ANOVAs with repeated measures were also used to examine the detailed VF measures (clusters, switches, and MCS). Prior to performing each statistic, the data error–covariance matrix was examined to ensure the structure that fit the data best. For the cluster measure and MCS measure, the error structure that fit the data best was the unstructured error structure. For the number of switches measure, the structure that fit the data best was the Toeplitz error structure. For all analyses, alpha levels were set at .05, Cohen’s standardized effect size is reported, and Tukey’s honestly significant difference test (Hinton, 2004) was used for all post-hoc comparisons reported.

Interjudge reliability. An independent rater scored a random 20% of the recordings. Separate scores for the different VF measures were obtained. The VF measures included scores for the number of clusters, the number of switches, and the MCS. Interjudge reliabilities, calculated with Pearson product–moment correlation coefficients, were high for the different measures. Interjudge reliability for the total VF score was 99%. The interjudge reliability was 91% for the number of clusters, 94% for the number of switches score, and 83% for the MCS score.

Phonological VF experiment. A significant group main effect for the number of words produced was obtained for the phonological VF task. The differences between the children with NH and the children with CIs were statistically significant, \( F(1, 38) = 10.45, p < .01, d = 1 \). The children in the CI group named fewer words on average compared with the NH group. The mean group scores for the total number of words produced in 1 min on the phonological task were 6.49 for the CI group and 8.96 for the NH group. No statistically significant difference was found among the three phonological subtasks (i.e., /t/, /l/, /f/). Scores for the phonological subtasks were compared across all participants in this study, \( F(2, 37) = 0.04, p > .05, d = 0.01 \). Within each group, the scores were similar across all three phonological subtasks (roughly six words per minute in the CI group and nine words per minute in the NH group). There was no interaction between group and phonological VF tasks, \( F(2, 37) = 0.63, p > .05, d = 0.21 \).

Semantic VF experiment. The children in the CI group generated significantly fewer words on the semantic task compared with the NH group, \( F(1, 38) = 5.06, p < .05, d = 1.12 \). The mean group scores for the total number of words produced in 1 min on the semantic VF task were 12.25 for the CI group and 15.10 for the NH group. No differences were found between the animal and food subtasks, \( F(1, 38) = 0.96, p > .05, d = 0.31 \). Scores for the semantic tasks (animals and food) were compared across all participants as well. The scores were similar within groups; the CI group generated approximately 12 names per minute and the NH group named approximately 14–15 words per minute across the categories subtasks. There was no interaction between group and semantic VF task, \( F(1, 38) = 1.97, p > .05, d = 0.64 \).

Detailed Analyses of the VF Responses—Clustering and Switching

Clustering analysis included identifying and scoring clusters in the child’s response. The analysis of switching examined the number of switches between words and clusters within the VF responses. Measures of clustering and switching analysis performed in the VF experiments, are summarized in Table 4.

Clustering and Switching—Phonological VF

Number of clusters. Children with CIs produced somewhat fewer clusters. This group difference in the number

<table>
<thead>
<tr>
<th>Variable</th>
<th>VF Phonological</th>
<th>Semantic VF</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>NH</td>
<td>CI</td>
</tr>
<tr>
<td>Number of clusters</td>
<td>3.75 (0.50)</td>
<td>4.95 (0.54)</td>
</tr>
<tr>
<td>Number of switches</td>
<td>12.7 (1.49)</td>
<td>18.1 (1.39)</td>
</tr>
<tr>
<td>Mean cluster size</td>
<td>2.04 (0.13)</td>
<td>2.21 (0.14)</td>
</tr>
</tbody>
</table>

Table 4. Group mean scores (and standard errors) for detailed analyses of the verbal fluency (VF) responses.
of clusters generated approached significance, $F(1, 38) = 3.70$, $p = .06$, $d = 0.51$. No significant task main effect was found for the number of clusters, $F(2, 37) = 3.13$, $p > .05$, $d = 1.03$; similar cluster sizes were found for the three subtasks $t, l, f$. In addition, there was no statistically significant interaction between group and number of clusters, $F(2, 37) = 2.42$, $p > .05$, $d = 0.80$.

Number of switches. Children with CIs generated significantly fewer switches in the phonological VF task, $F(1, 38) = 7.97$, $p < .01$, $d = 0.83$. No significant task main effect was found for the number of switches variable, $F(2, 37) = 1.28$, $p > .05$, $d = 0.42$. The interaction of group and number of switches was not significant, $F(2, 37) = 0.62$, $p > .05$, $d = 0.20$.

MCS. No group difference was observed for the MCS, $F(1, 38) = 2.53$, $p > .05$, $d = 0.28$. Both groups formed clusters of similar size with a mean cluster size of 2.04 in the CI group and 2.21 in the NH group. Children with CIs seemed to perform similarly to children with NH in the formation of clusters. Although the children in the CI group tended to generate fewer clusters in the phonological task, both groups used clusters of similar size. No significant task main effect was found for the MCS measure, $F(2, 37) = 1.17$, $p > .05$, $d = 0.38$. The interaction of group and MCS was not significant, $F(2, 37) = 0.68$, $p > .05$, $d = 0.22$.

### Clustering and Switching—Semantic VF

Number of clusters. No group difference was observed for the number of clusters, $F(1, 38) = 2.34$, $p > .05$, $d = 0.04$. No significant task main effect was found, $F(1, 38) = 3.13$, $p > .05$, $d = 1.02$. In addition, there was no statistically significant interaction between group and number of clusters in the semantic VF tasks, $F(1, 38) = 0.11$, $p > .05$, $d = 0.04$.

Number of switches. No group difference was observed for the number of switches, $F(1, 38) = 2.46$, $p > .05$, $d = 0.29$. No significant task main effect was found for the number of switches measure, $F(1, 38) = 2.86$, $p > .05$, $d = 0.93$. The Group × Number of Switches interaction was also not significant, $F(1, 38) = 0.90$, $p > .05$, $d = 0.29$.

MCS. No group difference was observed for the MCS measure, $F(1, 38) = 2.07$, $p < .05$, $d = 0.41$. Both groups formed clusters of similar size: Mean cluster size was 2.58 in the CI group and 2.73 in the NH group. No significant task main effect was found for the MCS measure, $F(1, 38) = 1.17$, $p > .05$, $d = 0.38$. The Group × MCS interaction was not significant, $F(1, 38) = 0.24$, $p > .05$, $d = 0.08$.

### Correlations With Background Factors in the CI Group

Pearson product–moment correlation coefficients were computed among results of the measures in the VF experiment and variables related to background factors in the CI group (age, TONI-3 nonverbal IQ, age at implantation, total time of experience with the CI device and language scores). The results of these correlations are reported in Table 5. Age at implantation and years of CI use were significantly correlated with performance on the semantic part of the VF task. Children implanted earlier named more words on the semantic VF task. Children who had used their implants for a longer duration of time also tended to perform better on the semantic VF task. Children who passed the language screening performed better on the semantic VF task compared with children who did not score within their age range.

### Discussion

Optimal performance on VF tasks requires a systematic search of the mental lexicon, word generation within a subcategory, and, when a subcategory is exhausted, switching to a new subcategory. This entails an adequate vocabulary (number of words and depth of knowledge) and lexical accessibility. The performance on phonological and semantic VF tasks relies on the hierarchical organization of words and their attributes in the participant’s mental lexicon. Successful performance on a VF task depends on the effectiveness of both automatic and controlled search processes (Hurks et al., 2006). Because typical early lexical development and organization relies on easy access to sound, and because even semantic VF relies on phonological information and hierarchical organization of the lexicon, children with CIs were expected to be at a disadvantage and show lower levels of performance, naming fewer words in phonological and semantic VF tasks. The results of Experiment 2 support this hypothesis. Children with CIs generated fewer words for both the phonological and semantic tasks. Results of the VF task uncovered specific differences in the lexical performance of children with CIs compared with children with NH, revealed in naming abilities. Children with CIs seemed to retrieve words less efficiently during the VF task compared with NH peers. The difference between the groups in the VF task may be more likely to lie mainly in slower retrieval processes rather than speed of planning for production, as indicated by picture-naming performance. The lack of a significant difference in overall picture-naming RT in Experiment 1 suggests that the slower naming produced by the children with CIs in the semantic VF task (almost three fewer words per minute), reflects poorer search strategies, which are required on the VF task. This can be explained by differences

### Table 5. Pearson correlation coefficients between background factors related to cochlear implant participants and performance on verbal fluency experiment.

<table>
<thead>
<tr>
<th>Background factor</th>
<th>Phonetic VF task</th>
<th>Semantic VF task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>.352</td>
<td>.355</td>
</tr>
<tr>
<td>TONI-3 IQ</td>
<td>−.043</td>
<td>.328</td>
</tr>
<tr>
<td>Age at implantation</td>
<td>.335</td>
<td>−.463*</td>
</tr>
<tr>
<td>Years of CI use</td>
<td>−.109</td>
<td>.514*</td>
</tr>
<tr>
<td>Language screening</td>
<td>.086</td>
<td>.481*</td>
</tr>
</tbody>
</table>

*p < .05.
in the breadth and organization of their vocabulary, as suggested for children with specific language impairment (Leonard, 2000). These retrieval deficits can be explained by models that posit fewer or weaker links between nodes (i.e., words) in memory or by weaker memory traces for learned words, resulting in fewer distinct entries in memory for those words (Kail, Hale, Leonard, & Nippold, 1984). In addition, compared with simple picture-naming tasks, VF tasks are more complex, requiring not only access of individual target words, but also words that are categorically related phonologically and semantically. Furthermore, they must access and produce clusters of words and rapidly switch focus in production across words or clusters.

In the VF task, there were overall differences in performance between the phonological and semantic tasks. All subjects (both CI and NH groups) tended to perform better on the semantic than the phonological VF task. These findings are consistent with other studies using phonological and semantic VF tasks (Riva et al., 2000). The VF phonological task is more difficult than the semantic VF because it requires greater organization and strategic capabilities as well as phonological awareness abilities (Riva et al., 2000).

Larger mean group differences were observed in the phonological VF task compared with the group differences in the semantic VF task. In addition, group differences on phonological and semantic VF tasks also emerged for the number of switches measure in the phonological VF task. Children with CIs demonstrated significantly fewer switches in the phonological VF task, whereas no group differences were found in the number of switches measure on the semantic task. Marginal group differences in the number of clusters measure were also observed in the phonological but not semantic VF task. Switching is considered an effortful process and is sensitive to age-related strategic retrieval abilities (Sauzéon et al., 2004). VF tasks are more challenging than single word naming and therefore allow the loci of the breakdown to be revealed.

The less efficient performance of some children with CIs, specifically on the phonological VF task, suggests the need to place more therapy resources in the phonological domain. Similar findings were observed in the picture-naming task; children with CIs showed larger RTs for longer words. Somewhat analogous findings have been reported in a group of Swedish children with CIs, who differed from their NH peers on a phonological but not semantic task (Löfkvist, Almkvist, Lyxell, & Tallberg, 2012). These observations can be attributed to differences in phonological organization of the mental lexicon. It may be related to fewer connections between words based on phonological features or weaker lexical-semantic links. Restricted lexical organization will affect the child’s language trajectory because lexical representations and connections serve as important foundations for higher level linguistic structures. These findings suggest that clinical effort should focus on enhancing the saliency of phonological and semantic characteristics of words and relations among words for children with CIs and aim to build lexical-semantic connections among words.

Summary and Concluding Discussion

Many children with CIs have language delays compared with NH age-mates (Fagan & Pisoni, 2010; Geers et al., 2003, 2009). Although many contributing factors to this delay have been identified, unaccounted-for variability in language attainment remains. One underlying mechanism that might play a role is lexical retrieval and lexical organization. This study examined lexical access and lexical organization for production using two naming experiments. The current study uncovered some similarities and differences in the naming abilities of children with CIs and those of NH peers. Children with CIs did not differ from the NH group in their accuracy and overall RT retrieving single names for pictures. In contrast, results of the VF naming task yielded clear differences. Children with CIs generated significantly fewer words than the NH group on both phonological and semantic VF tasks. Younger implanted children with more years of CI use, and those who had age-appropriate language scores, exhibited better performance on the semantic VF task, as expected (Nicholas & Geers, 2007; Uhler, Yoshinaga-Itano, Gabbard, Rothpletz, & Jenkins, 2011). Because the retrieval mechanism seems to be intact, the findings may be attributed to deficits in lexical organization due to limited representations or connections among words and their attributes.

The limited auditory input received by CI recipients may alter the typical development of the lexicon. This may affect lexical retrieval due to differences in the size of the lexicon, the development of phonological and semantic representations for individual words, and the connections among these words, reflected in the organization of the lexicon. Pisoni et al. (2008) suggested that the “CIs create highly degraded, ‘underspecified’ neural representations of the phonetic content and indexical properties of speech that propagate and cascade to higher processing levels” (p. 58). If these atypical representations cannot be reconstructed or refined at later stages of development, certain aspects of language knowledge and performance may continue to be atypical.

Nevertheless, the children with CIs did function as well as children with NH on some simpler tasks, such as picture naming. It seems that the VF task, which requires systematic lexical search of more than a single word under time pressure, is more apt to tap lexical organization than simple naming tasks. However, because this study involved off-line tasks, which do not reveal the moment-by-moment time course of lexical access and do not distinguish between access and underlying organizational deficits, our conclusions must be limited. Further analyses of the VF responses have the potential to reveal information about semantic networks (Kenett et al., 2013) and other naming tasks, such as cross-modal picture-word interference or picture-picture interference tasks, along with methods such as eye tracking, could provide more information (Schwartz et al., 2013).

The statistical analyses performed for these two experiments included correlations between various factors of interest in the CI group. These factors included age at
implantation and duration of CI use as well as language performance associated with performance outcome (naming abilities). Younger age at implantation and longer duration of CI use were associated with better performance in naming bisyllabic highly familiar words and also in naming words in the semantic VF tasks. Higher language scores were also associated with better performance in the semantic VF task.

These results are consistent with earlier studies demonstrating an advantage for early implantation and longer CI use on outcome. Earlier implantation and extended duration of CI use have been repeatedly associated with better speech and language performance in comprehension and production (Dettman, Pinder, Briggs, Dowell, & Leigh, 2007; Holt & Svirsky, 2008; Miyamoto, Hay-McCutcheon, Kirk, Houston, & Bergeson-Dana, 2008; Nicholas & Geers, 2007). There are several possible explanations for some of the smaller and nonsignificant correlations between participant characteristics of interest and the experimental tasks. In the picture-naming experiment, both groups performed similarly; therefore, we assume that the effects of age at implantation and duration of CI use were not very prominent due to the task not being challenging enough to reveal group or within-group differences. The absence of a significant correlation with phonological VF performance may be due to the specific participants in this study, who were required to have good speech intelligibility to fulfill task requirements, and their relatively older ages, compared with some other studies. It is possible that phonological variability in performance is less obvious in older children and that with a larger, younger, and more heterogeneous group of subjects, age at implantation and CI duration would have been found to correlate with the phonological task as well. We also found a strong significant correlation between CELF–3 screening results and performance on the semantic, but not phonological, VF task and not with the RT measures. Children who passed the language screening showed significantly higher scores on the semantic VF task. It is not surprising that scores on the CELF–3 screener correlated highly with the semantic VF task because the language skills that are examined with the CELF–3 screener are restricted mainly to semantic and grammatical aspects of language (and do not relate to phonological or lexical-semantic aspects). Therefore, we can conclude that naming measures and phonological VF have an added value to traditional language tests in that they provide additional information about lexical representation and their relation to semantic representation and knowledge; they can also help in the intervention process.

A more complete understanding of the language strengths and limitations of children with CIs is crucial for planning therapy. Lexical access and organization should be part of this planning. The present study demonstrated that some school-age children with CIs differ from their peers in lexical-semantic and phonological organization, specifically, in the breadth and depth of representations and the connections among words in memory. Therefore, intervention approaches that provide children with CIs a richer base of information about word’s meaning and form may enhance naming abilities and ease their communication process. Thus, habilitation should focus not only on increasing vocabulary size, but also on building systematic relations among words. This may need to extend well beyond early intervention to school-aged children who may no longer routinely receive such services. Although some children performed as well as their NH peers, it seems important to tailor intervention for each child by matching therapy to details of their linguistic knowledge and processing.

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