Journal of Deaf Studies and Deaf Education, 2016, 107–121

doi:10.1093/deafed/env060
Advance Access publication December 27, 2015
Theory/Review Manuscript

THEORY/REVIEW MANUSCRIPT

Vocabulary Knowledge of Children With Cochlear Implants: A Meta-Analysis

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Abstract

This article employs meta-analysis procedures to evaluate whether children with cochlear implants demonstrate lower spoken-language vocabulary knowledge than peers with normal hearing. Of the 754 articles screened and 52 articles coded, 12 articles met predetermined inclusion criteria (with an additional 5 included for one analysis). Effect sizes were calculated for relevant studies and forest plots were used to compare differences between groups of children with normal hearing and children with cochlear implants. Weighted effect size averages for expressive vocabulary measures ($g = -11.99$; $p < .001$) and for receptive vocabulary measures ($g = -20.33$; $p < .001$) indicated that children with cochlear implants demonstrate lower vocabulary knowledge than children with normal hearing. Additional analyses confirmed the value of comparing vocabulary knowledge of children with hearing loss to a tightly matched (e.g., socioeconomic status-matched) sample. Age of implantation, duration of implantation, and chronological age at testing were not significantly related to magnitude of weighted effect size. Findings from this analysis represent a first step toward resolving discrepancies in the vocabulary knowledge literature.

Over the last three decades, cochlear implants have improved the speech perception abilities of individuals with profound hearing loss. As a result, oral language outcomes have improved (Waltzman, Cohen, Green, & Rowland, 2002). One potential benefit of cochlear implantation frequently reported in the literature includes the opportunity for profoundly deaf individuals to learn more spoken words (e.g., James, Rajput, Brinton, & Goswami, 2009). However, the literature reports mixed findings regarding the ability of children with cochlear implants to "catch up" to their normal-hearing peers' level of vocabulary knowledge, particularly with regard to spoken vocabulary (e.g., Convertino, Borgna, Marschark, & Durkin, 2014; Nicholas & Geers, 2007; Nott, Cowan, Brown, & Wigglesworth, 2009). Children who develop large vocabularies in preschool tend to have better language, reading, and cognitive outcomes than children with smaller vocabularies (Marchman & Fernald, 2008). Thus, it is important to understand vocabulary development in children with cochlear implants relative to children with normal hearing to begin to establish expectations for lexical and academic development in children with cochlear implants. The purpose of this article is to systematically evaluate via meta-analysis whether children with cochlear implants demonstrate lower spoken vocabulary knowledge than their peers with normal hearing and the effect of comparison sample on that mean difference in vocabulary knowledge.

Vocabulary Development in Children With Cochlear Implants

High vocabulary knowledge (usually measured as the ability to receptively identify and name pictures) has been linked with higher academic and professional outcomes than low vocabulary knowledge in children with normal hearing (Duncan et al., 2007). The growth of vocabulary knowledge across the life span (e.g., Bloom, 2002) makes it difficult for those with delayed vocabulary knowledge to eventually "catch up" to peers. Even under optimal circumstances (very early identification and early access to surgery), children with congenital profound hearing

Received May 12, 2015; revisions received November 20, 2015; accepted November 24, 2015

loss who use cochlear implants do not gain access to sound until they are 12 months old (the age at which cochlear implantation is supported by FDA-labeled indications). As a result, children with cochlear implants do not have the opportunity to begin listening, and learning spoken language, until they are at least a year older than their normal-hearing peers. However, children with cochlear implants do not necessarily have a language-learning deficit that will keep them from acquiring vocabulary at a rate commiserate with peers. In addition, many children with cochlear implants have nonverbal cognitive skills that fall within the range of normal (Geers, Nicholas, & Sedey, 2003). Because cognitive abilities underlie vocabulary acquisition, children with cochlear implants may be well prepared to begin learning new words as soon as they gain access to sound.

However, children with cochlear implants face a disadvantage when trying to "catch up" to the vocabulary knowledge of peers with normal hearing. To develop enough vocabulary words to have an "average" vocabulary compared to children with normal hearing, children with cochlear implants must learn vocabulary words at a faster rate than children with normal hearing. Although preliminary evidence suggests that rate of vocabulary growth is malleable, it is unclear whether children with cochlear implants can sustain a vocabulary growth rate greater than that of their peers with normal hearing (Lund & Schuele, 2014).

It is crucial to determine whether children with cochlear implants should be expected to develop vocabulary knowledge comparable to their peers with normal hearing. Clinical professionals make decisions about service provision based on a child's rate of growth with a cochlear implant (Robbins, 2005). Parents and educators are counseled about the amount of progress a child with a cochlear implant is "expected" to make. The standards set for progress expectations will dictate how parents view their child's growth, what services a child receives, and possibly the acquisition of a second cochlear implant device (Lazaridis, Therres, & Marsh, 2010). Consequently, it is imperative that professionals set a reasonable benchmark for adequate progress in language skills, including vocabulary development. Further, if children are not expected to "catch up" to the vocabulary knowledge of their normal-hearing peers, this information must also be communicated to professionals and parents.

Vocabulary Outcomes of Children With Cochlear Implants

A review of the current literature yields conflicting results about the state of vocabulary knowledge in children with cochlear implants. Some studies indicate that children with cochlear implants, or subgroups of children with cochlear implants, have attained a normal level of vocabulary knowledge compared to peers or are likely to do so (Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Geers & Nicholas, 2013; Geers, Tobey, Moog, & Brenner, 2008; Hayes, Geers, Treiman, & Moog, 2009; Luckhurst, Lauback, & VanSkiver, 2013). Other studies indicate that children with cochlear implants do not develop vocabulary knowledge comparable to chronologically age-matched peers (Davidson, Geers, & Nicholas, 2014; El-Hakim et al., 2001; Holt & Kirk, 2005; Nott et al., 2009; Svirsky, Teoh, & Neuburger, 2004).

Many studies concluding that children with cochlear implants can attain vocabulary knowledge (e.g., receptively and expressively identify words) similar to age-matched peers with normal hearing stipulate that this result particularly applies to children who received cochlear implants at an early age. Hayes and colleagues (2009) assessed the receptive vocabulary growth of children ages 5–8 years old with cochlear implants who were students at an auditory-oral school. Growth trajectories predicted that children implanted before the age of 2 would reach the range of normal performance. Those children implanted after the age of 2 did not reach normal performance. Using growth curve modeling, Connor and colleagues (2006) similarly determined that by age 6, children who were implanted prior to 30 months achieved a mean standard score within the range of normal on receptive vocabulary measures. Geers and colleagues (2009, 2013) also found that children implanted before age 4 were more likely to achieve vocabulary scores within the range of normal on vocabulary measures by the time they enter school than children implanted at a later age. Luckhurst et al. (2013) recently compared the receptive and expressive vocabulary knowledge of children with cochlear implants who were, on average, 4.5 years old, to a sample of children with normal hearing matched for chronological age and nonverbal IQ. Children who were implanted before they were 30 months old attained vocabulary scores comparable to peers with normal hearing. Thus, there are a series of studies that predict children implanted at a young age have the potential to develop vocabularies similar to normal-hearing peers.

Another body of literature indicates that children with cochlear implants, as a group, will not develop vocabulary knowledge equivalent to that of their chronologically age-matched peers. El-Hakim and colleagues (2001) compared the expressive and receptive vocabulary growth curves of children between the ages of 2 and 12 years old implanted between 1988 and 1999 to children with normal hearing by calculating age-equivalent scores. They concluded that children with cochlear implants implanted before age 5 were developing at a rate that was consistent with children matched for listening experience. However, the children's vocabulary knowledge did not grow faster than vocabulary knowledge of children with normal hearing, so children with cochlear implants were unlikely to develop knowledge equivalent to chronologically age-matched peers. Similarly, Svirsky et al. (2004) used developmental trajectory analysis of children between the ages of 2 and 8 years to determine that even those children implanted before 2 years old were unlikely to attain vocabulary knowledge similar to chronologically age-matched peers with normal hearing. Holt and Kirk (2005) compared receptive vocabulary growth of children with cochlear implants between the ages of 4 and 8 years who also had mild cognitive delays to children with cochlear implants who had normal cognitive skills. Three years post-implantation, both groups continued to perform below the range expected for children of the same chronological age with normal hearing. Further, projected growth rates did not indicate that either group would "catch up" to the knowledge level of chronologically age-matched normal-hearing peers.

Some recent studies using a normal-hearing comparison group also suggest that vocabulary performance of children with cochlear implants is significantly different from children matched for chronological age. Davidson et al. (2014) assessed the receptive vocabulary knowledge of children with cochlear implants between the ages of 8 and 9 years who had good audibility (aided pure-tone-average threshold of at least 20 dBHL) and poor audibility (aided pure-tone-average threshold of more than 20 dBHL) with the vocabulary knowledge of children matched for chronological age with normal hearing. Both groups of children with cochlear implants demonstrated receptive vocabulary knowledge that was significantly lower than the vocabulary knowledge of children with normal hearing. Nott and colleagues (2009) evaluated the vocabulary growth of children with cochlear implants and children with normal hearing using parent-report diary methods. The children with normal hearing, who were matched for home language (English), geography, and educational placement (early childcare center), took significantly less time to reach the first 50 words, the first 100 words, and first word combinations from the onset of the first word as compared to the children with cochlear implants. Thus, children with cochlear implants appear to acquire vocabulary words even more slowly even than peers matched for listening experience.

Limitations of Vocabulary Measurement of Children With Cochlear Implants

Together, findings from current research offer conflicting information as to whether children with cochlear implants should be expected to attain vocabulary knowledge equivalent to peers with normal hearing. Differences in findings across studies may result from the use of different comparison groups (or lack thereof), measurement of vocabulary knowledge in differing domains, or differences in characteristics of the children participating in various studies.

Norm referencing

Many studies attempting to evaluate the vocabulary growth of children with cochlear implants use normative data from test publications rather than employing a direct comparison group of children with normal hearing (e.g., Connor et al., 2006; El-Hakim et al., 2001; Geers et al., 2009; Geers & Nicholas, 2013; Hayes et al., 2009). Theoretically, this methodology provides a measure of whether or not children with cochlear implants can attain scores within a "range of normal" as compared to peers. However, much evidence suggests that population characteristics (e.g., socioeconomic status and maternal education level) mediate vocabulary knowledge of children (Dollaghan et al., 1999; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). Although a test standardization sample is a valid and often nationally representative sample of performance for children of a particular age group, some studies indicate that the assumption of a normal distribution of vocabulary skill within age group is not representative of certain populations within that age group (e.g., Dollaghan et al., 1999; Qi, Kaiser, Milan, & Hancock, 2006). For example, Qi and colleagues (2006) assessed over 500 children from low-socioeconomic status homes and mid- to high-socioeconomic status homes and determined that children from different socioeconomic strata were better represented by multiple normal curves. That is, the pattern of vocabulary knowledge of children from low-socioeconomic status homes followed a normal distribution, but the mean performance for this group was 1.5 standard deviations below the expected mean for national norms. Similarly, Dollaghan and colleagues (1999) found a mean receptive vocabulary knowledge score nearly 1 standard deviation above the expected mean for children whose mothers were college educated. Use of a direct comparison group allows a researcher to control for factors other than age (such as education or socioeconomic status) to determine the effects of cochlear implantation on the vocabulary outcomes of children with cochlear implants.

Another limitation of current studies is the use of age-equivalent scores to draw conclusions (e.g., Chilosi et al., 2013; Connor et al., 2006; El-Hakim et al., 2001). Age-equivalent scores should not be used as precisely representative of a child's performance (for a review, see McCauley & Swisher, 1984). Age-equivalent scores do not represent a consistent metric: an age-equivalent score that is 1-year delayed for a child at age 6 is not the same as an age-equivalent score that is 1-year delayed for a child at age 3. As children age, the reliability of age-equivalent scores decreases. Thus, these scores do not adequately track progress in children and the validity of the conclusions of studies using them cannot be evaluated.

Domain differences

Studies attempting to characterize the vocabulary growth and achievement of children with cochlear implants have measured vocabulary knowledge with a variety of instruments. These instruments tend to sample constructs in the domains of either "receptive" or "expressive" vocabulary. It is possible that children with cochlear implants demonstrate a more pronounced delay in one domain versus the other.

Differences in receptive versus expressive vocabulary knowledge are well documented in other groups of children with communication disorders. A group of children identified as "late talkers" are characterized by slow expressive linguistic development prior to age 3, generally falling below the 10th percentile in vocabulary knowledge (e.g., Fenson et al., 2007; Paul, 1996). Those "late talkers" who demonstrate a discrepancy between receptive and expressive language knowledge (i.e., who do not demonstrate delayed receptive vocabulary skills) tend to develop expressive skills later that will fall in the range of normal (e.g., Ellis Weismer, 2007; Rice, Taylor, & Zubrick, 2008). Those children who exhibit delayed receptive as well as expressive skills, however, are at high risk for continued language delay (e.g., Ellis & Thal, 2008; Thal 2000). In this case, differences in receptive versus expressive vocabulary knowledge predict better overall language outcomes.

Children with other language disorders demonstrate the opposite relative discrepancy: children with autism spectrum disorder, Fragile X, and Down syndrome tend to have better expressive language skills than receptive skills (Hudry et al., 2010; Roberts, Mirrett, & Burchinal, 2001; Ypsilanti, Grouios, Alevriadou, & Tsapkini, 2005). This finding, however, does not indicate that children within these populations can say more words than they understand. Early language development in typically developing children is characterized by a tendency to acquire more receptive vocabulary words than expressive words (Fenson et al., 1994). A child who demonstrates relatively better expressive knowledge than receptive knowledge as compared to typically developing children is likely a child who only has words represented in his or her receptive as well as expressive lexicon. This type of child would not necessarily develop a large set of words that he or she only knows receptively. Therefore, a child with a relative receptive vocabulary deficit does not acquire a large receptive vocabulary compared to his or her expressive vocabulary.

Disagreement in the literature reporting vocabulary knowledge outcomes for children with cochlear implants may represent a difference in the domains sampled by vocabulary measures (i.e., receptive vs. expressive vocabulary). However, that literature does not conclusively indicate whether children with cochlear implants demonstrate better expressive versus receptive vocabulary knowledge. A systematic review is warranted to determine whether variability in outcome studies is the result of sampling two domains.

Child-level characteristics influencing vocabulary outcomes

Many child-level characteristics affect the vocabulary knowledge of children with cochlear implants. Researchers hypothesize that age at implantation affects vocabulary knowledge. Connor and colleagues (2006) applied growth curve analysis techniques to demonstrate that both listening experience and early age at implantation contribute to growth in language skills. Geers et al. (2008) found that those children implanted early had better language outcomes than children implanted later in childhood. Age of implantation contributed to language outcomes above and beyond the contribution of duration of implantation (i.e., listening experience), which is also a potential contributor to vocabulary outcomes. Similarly, Houston and colleagues (2012b) demonstrated that rapid word-learning performance in young children with cochlear implants correlates with age at implantation. The specific contribution of these child-level characteristics to vocabulary outcomes must also be examined: discrepancies between study findings about vocabulary in children with cochlear implants may reflect groups of children with different characteristics.

Objectives

The differing findings of vocabulary assessments of children with cochlear implants have not, to date, been systematically reviewed. The following questions guided this meta-analysis:

1. Does expressive vocabulary knowledge significantly differ between children with cochlear implants as compared to children with normal hearing?
2. Does receptive vocabulary knowledge significantly differ between children with cochlear implants as compared to children with normal hearing?
3. Does use of a norm-referenced comparison group (e.g., use of a norm-referenced sample) diminish the magnitude of the gap in vocabulary knowledge between children with cochlear implants as compared to children with normal hearing?
4. Does vocabulary domain assessed (receptive vs. expressive vocabulary) alter the magnitude of the gap in vocabulary knowledge between children with cochlear implants as compared to children with normal hearing?
5. Does age of implantation, duration of implantation, or chronological age at testing significantly relate to the magnitude of vocabulary knowledge difference between children with cochlear implants and children with normal hearing?

Method

Experimental Design

Meta-analysis, a research synthesis technique that allows for search and analysis replication, was selected for this review. Many research articles only report statistical significance, which is affected by sample size. Because of this, only reporting statistical significance levels across a group of studies can be misleading and lead to mixed results. Meta-analysis allows researchers to effectively pool the results of studies to increase statistical power applied to a research question (Cooper, Hedges, & Valentine, 2009).

Study Identification

To identify relevant studies, inclusion criteria, which included study design, participant characteristics, and outcomes measures, were determined by the author (see Table 1). First, the author and two research assistants conducted a database search in March of 2015 using Academic Search Complete by EBSCOhost and PsychINFO by EBSCOhost. Academic Search Complete includes abstracts for more than 13,200 publications, including peer-reviewed journals, non-peer-reviewed journals, and dissertation documents. PsychINFO contains abstracts from more than 2,100 publications, including journal articles, book chapters, technical reports, and dissertations. Article search terms were set to include cochlear implants, children, and vocabulary or lexicon. The search was configured to identify key words within the full text of articles available in English. Second, the author searched the references of articles from the database search that met inclusion criteria. Third, the author reviewed the Table of Contents from each journal that published an article meeting inclusion criteria from the year 1990 to present. Fourth, the author conducted a search of individual author names from studies meeting inclusionary criteria.

The initial search described above yielded 754 unique abstracts for review. Abstracts were screened for inclusion criteria by the first author. If necessary, the full-text document for an article was retrieved to confirm that a study did or did not meet inclusion criteria. This screening yielded 52 articles that met the initial set of inclusion criteria.

The author screened articles for age of participants. Prior to the 1994 Joint Committee on Infant Hearing (JCIH) position statement, newborn hearing screening was only recommended for infants deemed “at-risk” for hearing loss (Joint Committee on Infant Hearing, 1994). This recommendation resulted an average age of hearing loss identification of 30 months of age (Harrison & Roush, 1996). The JCIH 1994 position statement recommended screening of all newborn infants, and the JCIH 2000 revised position statement to capture a screening and follow-up rate of at least 95% of newborns (Joint Committee on Infant Hearing, 2000). Because early implantation has been associated with improved vocabulary outcomes for children with cochlear implants, this analysis only includes studies with participants who would have received a cochlear implant after the year 2000 (Connor et al., 2006). Because some studies were published outside of the United States, additional searches confirmed that participants in those countries also had access to systems of early identification and cochlear implantation.

In addition, the author screened these articles for those that included a normal-hearing comparison group. Many articles measuring the vocabulary knowledge of children with cochlear implants do not include a normal-hearing comparison group, particularly if vocabulary knowledge is not the focus of the article. Many articles also compare the performance of children with cochlear implants to published test norms. General test norms do not allow researchers to match participants for characteristics other than age. Therefore, to determine whether children with cochlear implants do catch up to peer knowledge levels using meta-analysis techniques, a comparison group was deemed necessary for article inclusion for research questions 1, 2, and 4. To analyze data to answer question 3, those studies meeting other inclusionary criteria but that used a norm-referenced comparison group were included in analysis. Meta-analysis requires the use of effect sizes to compare relative differences between groups; thus, a study without a comparison group cannot be effectively entered into a meta-analysis. This screening stage yielded 11 articles that met the established inclusion criteria for questions 1, 2, and 4. Analyses for question 3 included five additional articles. Table 2 identifies those studies excluded from analysis and the reason for exclusion (see Appendix).

Three graduate assistants served as additional reviewers. They independently determined eligibility of the 52 articles that met the initial inclusion criteria. Point-by-point agreement for

Table 1. Study inclusion criteria

Criteria	Description
Design	Comparison of children with cochlear implants to children with normal hearing matched for chronological age
	Published, unpublished, or dissertations
Participants	Use of at least one cochlear implant device
outcomes	At least one vocabulary outcome measure (e.g., receptive or expressive)
	Use of validated measure
	Any type of measure (e.g., parent report or observational)

study criteria across all 52 studies was calculated and yielded agreement of 100%.

Data Extraction and Analysis

PDF files for each of the articles that met inclusion criteria were obtained and maintained by the author. Information was extracted from each article using a detailed coding protocol. The author and a research assistant independently coded each full article for the variables listed in Table 3. Point-by-point agreement was calculated for each variable across the seven studies, yielding 98.52% agreement. The author's study coding was used for final analysis.

Description of included studies

Characteristics of those studies included in this analysis are summarized in Table 4. Sample size ranged from 34 to 158 participants and average participant age ranged from approximately 49 to 109 months. The mean age of cochlear implant activation for participants in cochlear implant groups ranged from 16 to 46.5 months. No study reported the inclusion of children with developmental delays. All studies included only those children developing oral language skills as a primary modality of communication (i.e., children who did not use sign language as their primary mode of communication). Most studies that met inclusion criteria for this meta-analysis used norm-referenced assessments to assess the constructs of expressive and/ or receptive vocabulary. Within these studies, standard scores were used to compare groups. Caselli and colleagues (2012) assessed participants using the Lexical Phonological Test (Vicari, Marotta, & Luci, 2007), which assesses lexical comprehension and production of Italian words. Standard scores for this assessment were not reported, so raw scores were used for analysis. Because Caselli et al. (2012) included scores from a normal-hearing control group matched for age, effect sizes from different raw scores are appropriate to enter into meta-analysis calculations.

An aforementioned strength of studies with control groups (as compared to a norm-referenced comparison) is that those studies are able to control for group-matching variables other than chronological age. Of those studies included in this meta-analysis, each matched for at least two additional variables in addition to age. Nine studies also matched children for geographical location, 11 matched children for either socioeconomic status or maternal education level, 5 matched children for gender, 4 matched children for nonverbal cognition performance, 1 matched children for reading ability, and 1 matched children for ethnicity. Table 4 indicates matching variables for each individual study.

Data Synthesis

Effect sizes for each study were estimated using information about standardized mean differences between the group of children with cochlear implants and the group of children with normal hearing using the formula:

$$d = \frac{\bar{Y}_1 - \bar{Y}_2}{S_{\text{within}}}$$

where S_{within} is the within-groups standard deviation, pooled across groups:

$$S_{\text{within}} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

This effect size estimate for d was converted to Hedges' g to account for small sample bias (Hedges, 1981):

$$g = \left[1 - \frac{3}{4N - 9}\right]d$$

Some studies reported multiple outcome measures (both receptive and expressive vocabulary). One of those studies, Johnson and Goswani (2010), also divided students into groups who received cochlear implants early in life, and those who received them later. Davidson et al. (2014) also divided participants based on speech recognition scores into a "good audibility" and "poor audibility" group. To capture the effects of studies measuring multiple outcomes, multiple analyses were conducted based on the outcome variables to judge the results of expressive and receptive vocabulary domain sampling separately. That is, one effect size for each language construct was calculated. However, to calculate the overall meta-analysis scores for vocabulary knowledge as one domain, steps were taken to ensure that those studies with two outcome variables or more than one group were not given more weight than studies with one outcome variable. Thus, the variance of a composite score for each of these studies was calculated to create a synthetic composite term to enter into the meta-analysis. The overall aggregated effect size reported in Results section includes these composite terms (Borenstein, Hedges, Higgins, & Rothstein, 2009).

Statistical model for analysis

A random effects model was used to analyze effect sizes. The mean effect size for the random effects model was calculated by weighting each adjusted effect size by the inverse of its variance (the sum of the estimate of variance associated with participant-level sampling error and the estimate of between-studies variance component). Calculations were completed using OpenMetaAnalyst software (Wallace et al., 2012). Additional random-effects meta-regression analyses were calculated using age of implantation, duration of implantation, and then chronological age as covariates.

Table 2. Studies excluded from meta-analysis for research questions 1, 2, and 4 after meeting initial screening criteria

Study	Reason for exclusion
Bergeson, Pisoni, and Davis (2003)	Comparison between groups with hearing loss
Chilosi et al. (2013)	Only age-equivalent scores reported
Connor et al. (2000)	Comparison between groups with hearing loss
Connor et al. (2006)	Only age-equivalent scores reported
Convertino et al. (2014)	Participants were college students (born before 2000)
Coppens et al. (2013)	Measured lexical decision making, not general vocabulary knowledge
Dawson et al. (1995)	Comparison within group with hearing loss
Dillon, De Jong, and Pisoni (2012)[a]	Comparison with normative data for hearing children from test
Easterbrooks et al. (2008)	Comparison within group with hearing loss
Edwards et al. (2011)	Group with hearing loss contained both children with cochlear implants and hearing aids
El-Hakim et al. (2001)	Comparison between groups with hearing loss
Ertmer, Strong, and Sadagopan (2003)	Only one participant; no comparison group
Ertmer and Inniger (2009)	Only two participants; no comparison group
Fagan and Pisoni (2010)[a]	Comparison with normative data for hearing children from test
Fitzpatrick et al. (2012)	Comparison between groups with hearing loss
Geers et al. (2009)[a]	Comparison with normative data for hearing children from test
Geers and Nicholas (2013)[a]	Comparison with normative data for hearing children from test
Geers, Spehar, and Sedey (2002)	Comparison between groups with hearing loss
Hayes et al. (2009)	Did not provide means or standard deviations
Holt, Kirk, and Hay-McCutcheon (2011)	No report of means from vocabulary testing
Houston et al. (2005)	Experimenter-created measure for rapid word learning assessment, not general vocabulary knowledge
Houston et al. (2012)	Normal-hearing comparison group administered different vocabulary assessment than cochlear implant group
Huttunen and Ryder (2012)	Measured mentalizing vocabulary, not general vocabulary knowledge
Iwasaki et al. (2012)	Comparison between groups with hearing loss
James et al. (2009)	Only age-equivalent scores reported
Kenett et al. (2013)	Experimenter-created measure for verbal fluency, not general vocabulary knowledge
Kosaner et al. (2013)	Measured time to acquire first 100 words, not general vocabulary knowledge
Lofkvist et al. (2012)	Measure assessed verbal fluency, not general vocabulary knowledge
Lu et al. (2013)	Assessed validity of a vocabulary test without direct normal-hearing comparison
Nicholas and Geers (2008)	Means/standard deviations not provided
Nittrouer et al. (2013)	Reported on same participants as Nittrouer et al. (2014)
Oh and Kim (2004)	Comparison within participants with hearing loss
Ostojic et al. (2011)	Validity of vocabulary measure unclear; means and standard deviations not provided
Sarant and Garrard (2014)[a]	Comparison with normative data for hearing children from test
Spencer (2004)	Comparisons within group with hearing loss
Svirksy, Teoh, and Nueburger (2004)	Comparison between groups with hearing loss
Tomblin et al. (1999)	Comparison between groups with hearing loss
Unterstein (2010)	Dissertation document with participants reported in Luckhurst et al. (2013)
Warner-Czyz, Davis, and Morrison (2005)	Only one participant
Wass et al. (2008)	Measure assessed response latency rather than general vocabulary knowledge
Wechsler-Kasi, Schwartz, and Cleary (2014)	Experimenter-created measure not assessing general vocabulary knowledge

Note. [a]Indicates study was only excluded as a result of using normative data comparisons; these studies were included in the analysis for research question 3.

Results

The first research question of this meta-analysis addressed whether children with cochlear implants demonstrated lower expressive vocabulary knowledge than children with normal hearing. To answer this question, effect sizes between groups for each study (or for each construct/subgroup within a study) were compared. Effect sizes (*d*) ranged from +0.34 to −1.063. Figure 1 is a forest plot showing weighted effect sizes (*g*) for the mean difference for each study containing expressive vocabulary measures. The weighted effect sizes take into account the size and significance of each study. The placement of each box represents the mean difference in scores between children with cochlear implants and children with normal hearing. Lines through the boxes represent a 95% confidence interval around the means, and the size of the box indicates the relative sample size, and thus weighting, for each study. The overall aggregated effect size demonstrates that children with cochlear implants

Table 3. Characteristics of studies included in analysis

Characteristic	N	%
Publication type		
Published	16	100
Unpublished	0	0
Country		
United States	11	70
Italy	1	6
Sweden	1	6
Great Britain	1	6
Netherlands	1	6
Australia	1	6
Socioeconomic status		
Primarily middle class	6	37
Mixed lower/middle class	0	0
Not reported	10	62
Average maternal education		
High school	0	0
More than high school	10	62
Not reported/unclear reporting	6	37
Type of measure		
Parent report	0	0
Norm referenced	15	94
Experimenter created	1	6
Construct measured		
Receptive vocabulary	6	38
Expressive vocabulary	3	18
Both	7	44

Note. Most studies reported either socioeconomic status or maternal education levels of participants, but not both. All groups using matched samples were geographically matched within studies. Several studies matched participants on other variables as well (e.g., age and gender).

performed lower than peers with normal hearing by an average of 11.99 points on expressive vocabulary tasks ($p < .001$).

The second research question addressed whether children with cochlear implants demonstrated lower receptive vocabulary knowledge than children with normal hearing. To answer this question, effect sizes between groups for each study (or for each construct/subgroup within a study) were compared. Effect sizes (d) ranged from −0.46 to −2.00. Figure 2 is a forest plot showing weighted effect sizes (g) for the mean difference for each study containing receptive vocabulary measures. The overall aggregated effect size demonstrates that children with cochlear implants performed lower than peers with normal hearing by an average of 20.33 points on receptive vocabulary tasks ($p < .001$).

The third research question considered whether studies using a norm-referenced comparison group diminish the magnitude of the gap in vocabulary knowledge between children with cochlear implants and children with normal hearing. To answer this question, additional calculations were completed with studies from questions 1 and 2 that used a norm-referenced assessment. Instead of using data from the comparison group (which, in every article, was matched on factors above and beyond chronological age), this analysis used normative comparison data (assuming a standard score of 100 with a standard deviation of 15). Five additional studies from the initial search were also added to this analysis: these studies were initially excluded for lack of a normal-hearing comparison group. Effect sizes between the group of children with cochlear implants and the normative sample were calculated for each study. Effect sizes (d) for the expressive vocabulary analysis ranged from +0.31 to −0.61. Figure 3 is a forest plot showing weighted effect sizes (g) for the mean difference for the seven studies containing norm-referenced expressive vocabulary measures. The overall aggregated effect size demonstrates that children with cochlear implants performed lower than peers with normal hearing by an average of 6.81 points on expressive vocabulary tasks ($p < .001$). Use of a norm-referenced comparison group thus diminished the mean standard score point difference between the groups from 11.99 points to 6.81 points. However, statistically the confidence intervals for these averages overlap by a couple of points, meaning that the difference approaches but does not confirm statistical significance.

Effect sizes (d) for the receptive vocabulary analysis ranged from +0.09 to −2.11. Figure 4 is a forest plot showing weighted effect sizes (g) for the mean difference for the seven studies containing norm-referenced expressive vocabulary measures. The overall aggregated effect size demonstrates that children with cochlear implants performed lower than peers with normal hearing by an average of 9.06 points on receptive vocabulary tasks ($p < .001$). Use of a norm-referenced comparison group thus diminished the mean standard score point difference between the groups from 20.60 points to 9.06 points. Confidence intervals for these two difference calculations do not overlap, indicating that the difference created by using a different comparison group is statistically significant. In this case, use of a norm-referenced comparison group makes children with cochlear implants appear closer to a “normal” range of vocabulary knowledge than use of a more tightly matched control group.

The fourth research question considered whether vocabulary domain, expressive or receptive vocabulary, alters the magnitude of the gap in vocabulary knowledge between children with cochlear implants as compared to children with normal hearing. The weighted effect size average for receptive language measures was larger than the weighted effect size for expressive language measures. However, confidence intervals for each construct overlapped by 4 points, indicating these effect sizes for the two constructs were not statistically significantly different.

The fifth question considered whether age of implantation, duration of implantation, or chronological age at testing related to the magnitude of vocabulary score difference between children with cochlear implants and children with normal hearing. To answer this question, meta-regression analyses were calculated using weighted effect sizes as dependent variables and age of implantation, duration of implantation, or chronological age at testing as independent variables. Results revealed that neither age of implantation, duration of implantation, nor chronological age at testing was significantly related to magnitude of weighted effect size ($b_1 = -0.035$; $p = .261$; $b_1 = -0.024$; $p = .11$; $b_1 = -0.017$; $p = .08$). Because chronological age is confounded with duration of implantation, the meta-regression analysis using chronological age was calculated separately from the analysis with age and duration of implantation.

Sensitivity Analysis

To ensure that results were not compromised by the inclusion of studies that assessed receptive and expressive using many different measures, a sensitivity analysis was performed. Analyses were run for expressive vocabulary knowledge including only those studies using the American-English version of the Expressive One Word Picture Vocabulary Test (Brownell, 2000a, 2000b) or the Expressive Vocabulary Test (Williams, 2007) and for receptive vocabulary knowledge

Table 4. Individual study characteristics

Study	CI group *n*	NH group *n*	Matching variables	Focus of study	Mean age CI group (months)	Mean age at CI activation	Bilateral versus unilateral CI	Vocabulary measure(s)	Construct measured
Ambrose et al. (2012)	24	23	Maternal education, age, geography	Early literacy skills	49.46	20.96	11/13	PPVT-4	Receptive
Boons et al. (2013)	70	70	Gender, age, geography, SES	Vocabulary, grammar	86	20	27/43	EOWPVT	Expressive
Caldwell et al. (2013)	27	19	Age, geography, SES	Speech perception	81	21	18/9	EOWPVT	Expressive
Caselli et al. (2012)	17	17	Age, geography, SES, maternal education	Vocabulary, grammar	54	16	9/8	LPT	Receptive and expressive
Davidson et al. (2014)	101	47	Age, geography, SES	Word learning, vocabulary	107.52	24.6	53/47	PPVT-3	Receptive
Dillon et al. (2011)	27	Norm	N/A	Phonological awareness, reading, vocabulary	109.2	30	Not reported	PPVT-3	Receptive
Fagan and Pisoni (2010)	23	Norm	N/A	Vocabulary	109.2	30	Not reported	PPVT-3	Receptive
Geers et al. (2009)	153	Norm	N/A	Spoken language	70	28		PPVT-3; ROWPVT; EVT-2; EOWPVT	Receptive and expressive
Geers and Nicholas (2013)	60	Norm	N/A	Spoken language	126	22.7	29/31	PPVT-3; EOWPVT	Receptive and expressive
Johnson et al. (2010)	39	19	Geography, reading ability	Phonological awareness, vocabulary	121.5	46.5	Not reported	BPVS; EOWPVT	Receptive and expressive
Lofkvist et al. (2014)	34	39	Gender, age, geography, cognition	Vocabulary	92	22	33/1	PPVT-3 (Swedish version)	Receptive
Luckhurst et al. (2013)	9	42	Gender, age, geography, ethnicity, SES	Vocabulary	58.3	19.2	6/3	PPVT-4; EVT-2	Receptive and expressive
Nittrouer et al. (2014)	55	49	Age, gender, SES, cognition	Nonword repetition	103	20	28/27	EOWPVT	Expressive
Sarant and Garrard (2014)	70	Norm	N/A	Parenting stress, language	79.2	18.6	54/16	PPVT-4	Receptive
Schorr et al. (2008)	39	37	Gender, age, cognition, SES	Vocabulary, grammar	108	35.64	Not reported	PPVT-3; EVT	Receptive and expressive
Walker et al. (2013)	24	24	Age, geography, maternal education, cognition	Word learning	58.32	20.16	13/11	PPVT-3	Receptive

Note. CI = cochlear implant; NH = normal hearing; norm = used norm-referenced comparison; SES = socioeconomic status; BPVS = British Picture Vocabulary Scale (Dunn, Dunn, Wheton, & Pintilie, 1997); EOWPVT = Expressive One-Word Picture Vocabulary Test (Brownell, 2000a, 2000b); EVT = Expressive Vocabulary Test (Williams, 2007); LPT = Lexical Phonological Test (Vicari, Marotta, & Luci, 2007); PPVT-3 = Peabody Picture Vocabulary Test, Third Edition (Dunn & Dunn, 2007); PPVT-4 = Peabody Picture Vocabulary Test, Fourth Edition (Dunn & Dunn, 2007); ROWPVT = Receptive One Word Picture Vocabulary Test (Brownell, 2000a, 2000b).

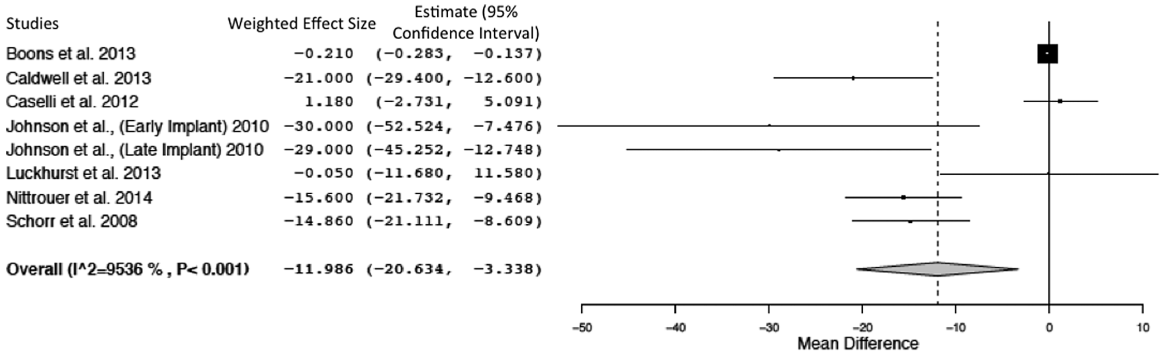

Figure 1. Forest plot of mean difference in scores on expressive vocabulary tasks for children with cochlear implants versus children with normal hearing.

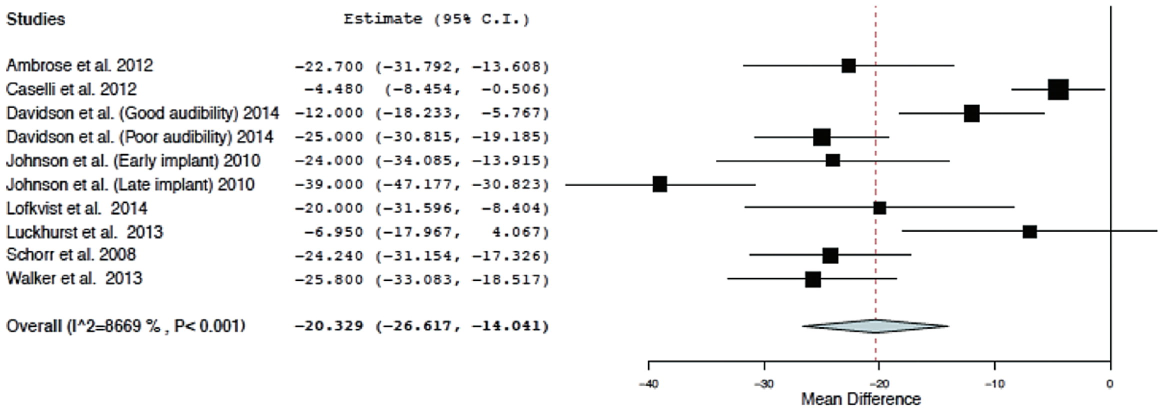

Figure 2. Forest plot of mean difference in scores on receptive vocabulary tasks for children with cochlear implants versus children with normal hearing.

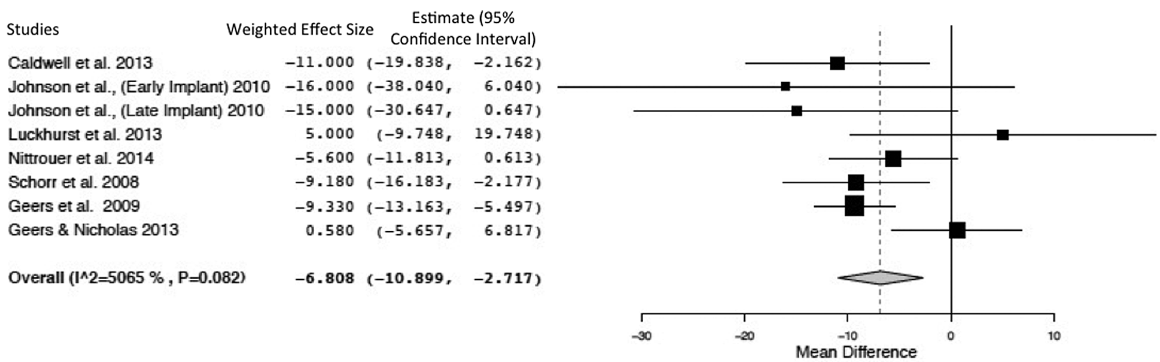

Figure 3. Forest plot of mean difference in scores on expressive vocabulary tasks for children with cochlear implants versus test-specific normative data for children with normal hearing.

including only those studies using the American-English version of the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007) and the Receptive One Word Picture Vocabulary Test (Brownell, 2000a, 2000b). Expressive test analysis yielded an overall mean difference of −14.07 points (as compared to −11.99 in the analysis including all articles). Confidence intervals overlapped by more than 15 points, indicating the two analyses were not significantly different. Receptive test analysis yielded an overall mean difference of −19.89 points (as compared to −20.60 points in the analysis including all articles). Confidence intervals overlapped by more than 12 points, indicating the two analyses were not significantly different. Thus, results from this meta-analysis do not appear to have been unduly affected by inclusion of multiple measures of the vocabulary knowledge construct.

Discussion

This article sought to systematically evaluate whether children with cochlear implants demonstrate lower vocabulary knowledge than peers with normal hearing and whether use of a normative comparison group might alter the magnitude of that knowledge difference. A meta-analysis of studies of children with cochlear implants that included a normal-hearing control group revealed that, on average, children with cochlear implants demonstrate lower receptive and expressive vocabulary knowledge than children with normal hearing. Findings from this analysis represent a first step toward resolving discrepancies in the vocabulary knowledge literature.

On average, children with cochlear implants scored 11.99 points lower on measures of expressive vocabulary and 20.33

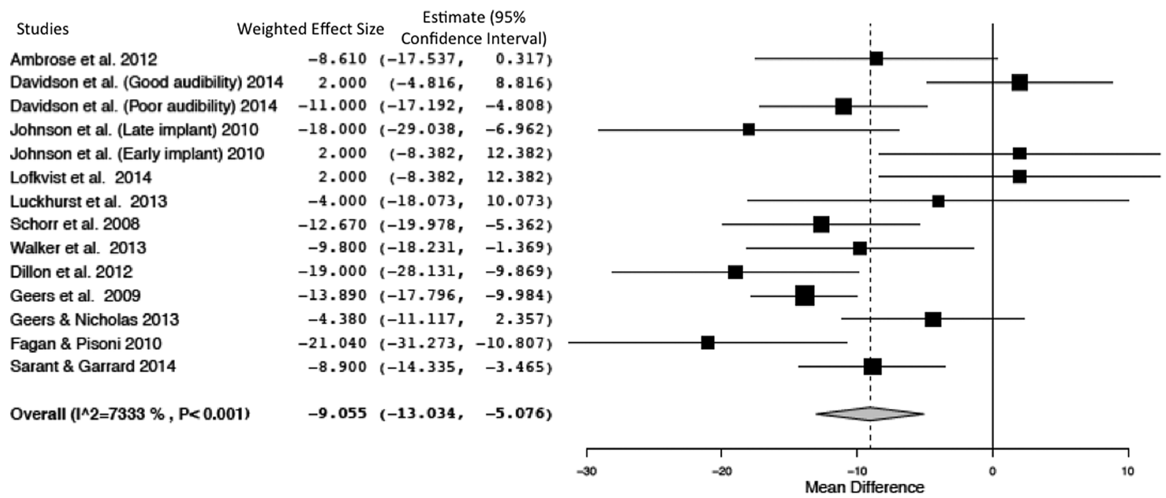

Figure 4. Forest plot of mean difference in scores on receptive vocabulary tasks for children with cochlear implants versus test-specific normative data for children with normal hearing.

points lower on measures of receptive vocabulary than children with normal hearing. This result is consistent with those studies reporting that children with cochlear implants demonstrate significantly different vocabulary knowledge than children with normal hearing (e.g., Davidson et al., 2014; El-Hakim et al., 2001; Nott et al., 2009; Svirsky et al., 2004). Other studies of vocabulary knowledge in children with cochlear implants have reported that children implanted prior to age 30 months are likely to attain vocabulary knowledge similar to normal-hearing peers of their same age (Connor et al., 2006; Hayes et al., 2009). Studies included in this meta-analysis reported mean ages of implantation that ranged from 16 to 46.5 months. Thus, even when children implanted prior to 30 months of age represented a majority of the participants, children with cochlear implants still demonstrated delayed overall vocabulary knowledge.

This analysis did not find a significant difference between receptive vocabulary and expressive vocabulary outcomes for children with cochlear implants. However, fewer studies were included in the expressive vocabulary subanalysis than in the receptive vocabulary sub-analysis. It is possible that the inclusion of more studies would have increased the likelihood of a significant difference between these constructs. Additionally, the confidence interval for expressive vocabulary was much larger than the confidence interval for receptive vocabulary. The trend demonstrated by this analysis indicates that receptive vocabulary knowledge may be more delayed for children with cochlear implants relative to children with normal hearing than expressive vocabulary knowledge. As a result of audibility difficulties, it is possible that when a child with a cochlear implant finally does learn a new vocabulary word, that word is as likely to become part of the expressive as well as receptive vocabulary. Because children with normal hearing tend to develop, at least initially, a larger receptive vocabulary than expressive vocabulary, children with cochlear implants would look more impaired relative to receptive vocabulary when compared to normal-hearing peers. This finding appears consistent with similar trends in other language-impaired populations, including preschoolers with autism spectrum disorder (Hudry et al., 2010). However, given the limited number of studies included in the analysis of expressive vocabulary knowledge, no conclusion can be drawn. Further, poorer receptive knowledge may reflect properties of a test rather than a quantitative difference in vocabulary knowledge. A receptive vocabulary measure may be biased against children with cochlear implants: if the child does not clearly hear the target word spoken by the examiner, he or she may be more likely to select the wrong response. Further, tests in this study were developed for hearing children and may not have taken into consideration particular needs of children with hearing loss.

Further analysis reveals that the magnitude of difference in vocabulary knowledge between children with cochlear implants and children with normal hearing does not significantly relate to age of implantation, duration of implantation, or age at testing. That is, groups of children who receive cochlear implants earlier in life are not likely to have vocabulary scores that are closer to those of same-age peers. This particular finding is consistent with those studies reporting that even older students demonstrate a lag in vocabulary knowledge compared to peers with normal hearing (e.g., Convertino et al., 2014). However, it is possible that duration of implantation begins to matter more as children gain more experience. The average age range of children was weighted toward studies including elementary school-aged children. Thus, the age range of this study may have diminished the contribution of duration of implantation to vocabulary outcomes.

Child-level factors beyond age of implantation, duration of implantation, and chronological age may contribute to the persistence or appearance of a vocabulary delay for children with cochlear implants. Individually, children with hearing loss, as a result of auditory deprivation, may not develop skills that facilitate word learning in the same way as children with normal hearing (Houston et al., 2012a). For example, there is mounting evidence that children with hearing loss demonstrate deficits in auditory-visual signal integration, a skill that is critical for learning vocabulary from one's environment (e.g., Bergeson, Houston, & Miyamoto, 2010). A child having a hearing loss may also affect the quality of information he or she receives from his or her environment: for example, parents of a child with hearing loss may not provide language-learning cues to those children in the same way as parents of children with normal hearing (Lund & Schuele, 2015). A hearing loss may also affect a child's ability to learn incidental language. Children with normal hearing frequently learn words via incidental exposure (e.g., Coyne, Simmons, Kame'enui, & Stoolmiller, 2004; Hart & Risley, 1995), whereas children with hearing loss may learn fewer words via this type of input (e.g., Lund & Douglas., under review). Finally, a child with hearing loss may also come from a family speaking more than one language at home. Children from bilingual homes may demonstrate different vocabulary growth trajectories than children from monolingual homes, and most vocabulary measures are currently unable to account for differences related to bilingualism (Bedore, Pena, Garcia, & Cortez, 2005).

Educational and Clinical Implications

This review serves as a preliminary basis for establishing lexical growth expectations for children with cochlear implants. Although the data support early implantation as it relates to vocabulary knowledge, there is no evidence that early implantation ensures that a child will "catch up" to his or her same-age peers. Average testing age for the studies included in this analysis ranged from 46.61 to 109.20 months. Thus, children with cochlear implants, even those implanted early, likely do not enter school with comparable vocabulary knowledge to their peers and often do not "catch up" in vocabulary knowledge quickly. It may not be reasonable to expect most children with cochlear implants to be able to catch up to the vocabulary knowledge of children with normal hearing.

Parents and professionals should prepare to accommodate the delayed vocabulary knowledge of children with cochlear implants via intervention strategies, such as pre-teaching new academic vocabulary prior to a lesson. In addition, these findings support a need for early intervention to begin mitigating the effects of low vocabulary knowledge on outcomes for children with cochlear implants. Prior to cochlear implantation, for example, parents may consider using a visual means of communication, such as sign language, with a child with hearing loss. Research to date indicates that early exposure to language, regardless of modality, improves later language outcomes (Davidson, Lillo-Martin, & Pichler, 2014; Hassanzadeh, 2012).

Research Implications

Norm referencing

Discrepancies between findings from this meta-analysis and findings from other studies may be the result of research methodology. Many studies reporting children with cochlear implants can attain the same level of vocabulary knowledge as children with normal hearing use a test's normative sample as a comparison group. Using norm referencing as a means of comparison does not allow researchers to control for other important variables, including nonverbal cognition and socioeconomic status. The results of this meta-analysis support that control of these variables and others, such as gender and geographical location, via comparison to an actual control group yields somewhat different results. Although a difference of 11.99–20.33 points could still indicate that children with cochlear implants score "within the range of normal" on a norm-referenced test, the difference between the two groups is likely still clinically significant. Future studies evaluating the growth trajectory of vocabulary knowledge in children with cochlear implants should apply a control group methodology to research questions to draw valid conclusions.

Limitations and Future Directions

Limitations of this review constrain the conclusions that can be drawn from its results. First, the number of studies included in this meta-analysis was relatively small. Because this analysis was limited to those studies that included a control group, only 11 studies qualified to be entered into analysis. However, the power of statistical analysis of meta-analysis procedures is not dictated by number of studies included alone: the estimated population effect size, the number of participants in each study, and the Type I error rate all contribute to power estimates. The number of studies (and therefore, participants) included in this meta-analysis exceed the number necessary to generate this review (Valentine, Pigott, & Rothstein, 2010).

Second, the limited amount of information available about vocabulary knowledge of children with cochlear implants did not allow the author to control for intervention history of participants. It is possible that some intervention methodologies are more likely to increase vocabulary knowledge than others. Future works may consider the impact of intervention history on the vocabulary achievement of children with cochlear implants. In addition, future works may consider studying more closely interventions that provide sign language input to children with hearing loss prior to cochlear implantation to minimize periods of language deprivation.

Third, children with cochlear implants present with a variety of etiologies, devices, additional disabilities, and family situations. The results of this study only relate to a subgroup of children with cochlear implants, who were mostly implanted early and had no additional disabilities. Families in these studies also tended to have at least middle-class socioeconomic status or parents with some college education. It is likely that the social and educational circumstances of participants in this meta-analysis only apply to a limited group of children who receive cochlear implants. To set expectations for vocabulary size in children with cochlear implants, researchers need to establish expectations for different subgroups of implanted children (e.g., children with additional disabilities, children from low-socioeconomic status families). In addition, research could consider how technical standards for implantation vary across countries and may affect outcomes.

Despite these limitations, this review of the current literature calls into question the idea that children with cochlear implants can develop vocabulary knowledge equivalent to their typically developing peers with normal hearing. Further work needs to be completed to establish appropriate expectations for lexical acquisition of children with cochlear implants and to determine ways of altering the trajectory of vocabulary growth in children with cochlear implants. From a research standpoint, investigators must evaluate vocabulary growth (using a variety of measures) in a longitudinal study that includes control groups with normal hearing. From an educational standpoint, professionals need additional information regarding lexical acquisition in children with cochlear implants according to individual child characteristics, such as age of implantation and instructional program. Professionals must, if possible, find ways to improve vocabulary knowledge in this population to interrupt the adverse consequences of limited vocabulary knowledge on reading and academic achievement.

Conflicts of Interest

No conflicts of interest were reported.

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