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A multilingual analysis of spelling among children with cochlear implants

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Abstract

This study examines the spelling of nine elementary school children with cochlear implants (CIs) who use spoken language, and compares their performance with children who have typical hearing and children who are hard of hearing (HH). Compared to children with typical hearing, children with CIs did not produce a significantly different percentage of misspelled words ($p = 0.431$, $d = 0.38$), but their spelling errors comprised significantly lower percentages of homophone substitutions ($p = 0.019$, $r = 0.61$) and legal vowel errors ($p = 0.011$, $r = 0.61$). Children with CIs and children who are HH did not produce a significantly different percentage of misspelled words ($p = 0.521$, $d = 0.31$) or a significantly different distribution of categorical spelling errors. Results suggest that children with CIs utilize similar linguistic strategies as their peers who are HH but different strategies than peers with typical hearing when attempting to spell unfamiliar words.

Over the last century, evolving views of English orthography and spelling have changed our understanding of the influence of deafness on the development of spelling. Traditionally, English was perceived as “unphonetic” due to sound-to-letter inconsistencies. Therefore deafness, with its reliance upon visual memory, was presumed to be more conducive than typical hearing for learning to spell in an orthography that lacked phonemic-graphemic regularity (Gates & Chase, 1926; Templin, 1948). Contemporary views consider English orthography to have robust morphophonemic regularity (Chomsky, 1970; Katz & Frost, 1992), and spelling is viewed as a complex skill that requires integration of multiple domains of oral and written language (Berninger, Abbott, Nagy & Carlisle, 2010; Masterson & Apel, 2010). Given the difficulties children with cochlear implants (CIs) have acquiring oral and written language (Geers & Hayes, 2011; Nitttrouer & Caldwell-Tarr, 2016), it is reasonable to assume the presence of deafness would introduce resistance, rather than conductance, to the development of spelling. Using a multilingual framework of analysis that reflects contemporary views of spelling (Berninger et al., 2006; Masterson & Apel, 2010), the purpose of this exploratory study was to test this assumption and examine the spelling of children with CIs to better

understand the relationships between their spelling errors and linguistic underpinnings.

Spelling Accuracy of Children with CIs

Only a few recent studies have compared the spelling accuracy of children with CIs to peers with typical hearing. After controlling for age and reading comprehension, Hayes, Kessler and Treiman (2011) reported that children with CIs aged 6–12 years demonstrated equivalent performance in spelling error rates compared to their peers with typical hearing. In contrast, a group of 112 high school students with CIs performed significantly more poorly than peers with typical hearing, with nearly half of them scoring two or more standard deviations below the control group (Geers & Hayes, 2011). Apel and Masterson (2015) found that children with CIs performed significantly poorer than reading-matched peers without hearing loss on a standardized test of spelling. The limited research suggests that at least some children with CIs struggle with accuracy in their spelling, and that there is a need for further understanding of spelling among the population of children with CIs.

Spelling is a Language Skill

Spelling involves the integration of multiple linguistic processes. Both Triple Word Form Theory (Berninger et al., 2006) and Repertoire Theory (Masterson & Apel, 2010) propose that phonological awareness, orthographic awareness, and morphological awareness are all involved in spelling, with changes occurring in the way each is involved over the course of spelling development. In contrast to stage theories in which spellers progress sequentially from learning to integrate phonological, then orthographic and then morphological knowledge (Bear, Invernizzi, Templeton, & Johnston, 2003; Ehri, 2000), these conjoint theories posit that all forms of linguistic knowledge develop simultaneously from the beginning. As a result, the development of one source of linguistic knowledge undergirding spelling is not completely dependent upon the development of another (Apel, 2009). Increased efficiency in coordination among these linguistic domains, and success in spelling, is believed to be influenced by educational instruction and approaches (Berninger et al., 2010; Masterson & Apel, 2010).

Linguistic Underpinnings of Spelling

Phonological awareness

Phonological awareness includes the ability to recognize, discriminate, and manipulate the syllabic and phonological units that compose speech (Stahl & Murray, 1994). Phonological awareness skills are typically measured in tasks that require children to segment a word into sounds, blend sounds into words, or make judgments of phonological similarity or difference. Studies of phonological awareness among children with CIs suggest that phonological awareness does improve over time (James, Brown, & Brinton, 2005), but there may be a longer developmental course (Spencer & Tomblin, 2009). Children with CIs have been reported to have some phonological awareness skills on par with typical hearing peers such as sound matching (Ching & Cupples, 2015), rhyme awareness (Spencer & Tomblin, 2009) and syllable counting (Nitttrouer, Sansom, Low, Rice & Caldwell-Tarr, 2014). Nevertheless, many studies have indicated that children with CIs tend to perform more poorly than typical hearing peers on phonological awareness tasks related to phonemic structure (Ambrose, Fey, & Eisenberg, 2012; Dillon, de Jong, & Pisoni, 2012; Nitttrouer et al., 2014).

Phonological awareness supports successful sound-to-letter linkages required in spelling (Bourassa & Treiman, 2001). Reduced phonological awareness among children with CIs may have significant implications for language skills like spelling that are vulnerable to delayed development in sensitivity to phonological structure. Given the strong correlation between spelling and phonological tasks related to phonemic structure (i.e., phonemic awareness) among children with typical hearing (Ball & Blachman, 1991; Sunseth & Bowers, 2002), children with CIs may be at a distinct disadvantage in their use of phonology to support spelling.

Orthographic awareness

Orthographic awareness encompasses the understanding needed to represent oral language in written form. Apel (2011) notes that this implicit and explicit knowledge includes the stored mental graphemic representations of words, as well as the knowledge of rules and patterns governing the individual representation of words in print. Apel further describes that stored mental representations of words support the spelling of familiar words, while implicit knowledge of allowable letter combinations based on statistical patterns supports the spelling of unknown or less familiar words. A variety of measures have

been used to examine orthographic awareness among children with CIs. A small sample of elementary school children with CIs demonstrated no significant differences in real or nonsense word reading compared to hearing peers with matched age-equivalency reading scores (Apel & Masterson, 2015), but a sample of secondary school students demonstrated single word reading abilities approximately 3 years below chronological age (Harris & Terlektsi, 2011). Delays have also been reported among preschool children with hearing aids and CIs in foundational orthographic awareness skills of print knowledge and word concept knowledge (Werfel, Lund, & Schuele, 2015).

Compared to phonological awareness, the literature suggests that children with CIs may have milder difficulties in orthographic awareness, but further investigation is warranted to determine if any existing difficulties could be significant enough to impact spelling performance for at least some children.

Morphological awareness

Morphological awareness includes understanding of how written and spoken language represent the smallest units of meaning. This knowledge includes recognition of: (a) morphemes in a word, (b) the rules for adding affixes, (c) the ways affixes alter meaning, and (d) the ways groups of words with the same base word are related in meaning (Apel, 2014). A cross-linguistic systematic review identified 18 studies of children who were implanted prior to 3 years and revealed persistent deficits in both receptive and expressive morphological development (Halle & Duchesne, 2015). In particular, difficulties with bound morphemes (e.g., plural *_s*, third person singular *_s*) have been observed in language samples (Nicholas & Geers, 2007), narratives (Guo, Spencer, & Tomblin, 2013), and sentence completion tasks (Boons et al., 2013).

Morphological awareness provides additional information regarding statistically predictable patterns and facilitates systematic storage into the mental lexicon (Deacon, 2008). When children do not correctly use morphological elements in expressive language, as has been reported among children with hearing loss, they are also likely to struggle even more with morphology in written language (Scott & Windsor, 2000). Furthermore, reduced access to language secondary to hearing loss would be expected to influence the development of derivational morphology (word formation and principles governing the use of affixes), as has been observed for vocabulary development among children with typical hearing (Weisleder & Fernald, 2013). Although more research is needed, reduced awareness of morphological structure among children with CIs may result in inefficient storage of mental graphemic representations, difficulty with word formation during writing, and reduced ability to use semantic relatedness (e.g., assign and assignment; sign and signature) to inform spelling and word selection (Garcia, Abbott & Berninger, 2010).

In summary, the development of phonological, orthographic, or morphological awareness may be compromised among children with CIs. As each of these areas of linguistic awareness supports spelling, it is of interest to understand if particular linguistic deficits may influence spelling accuracy or the types of spelling errors produced by children. Such information would assist in the development of individualized intervention approaches for children who struggle with spelling.

Linguistic Influences on the Spelling Errors of Children with CIs

Given the complex linguistic underpinnings of spelling, traditional spelling assessments that focus on correct versus incorrect spelling of whole words are of limited value in determining why

some children struggle with spelling. Spelling metrics that examine the qualitative nature of misspellings may provide better insight into linguistic deficiencies contributing to spelling errors. Two studies have examined categorical spelling errors of children with CIs in comparison to peers with typical hearing. Hayes and colleagues (2011) reported that elementary children with CIs produced a similar percentage of transposition errors (e.g., “wrom” for “worm”), but significantly fewer phonologically plausible errors (defined as the correct sequential representation of all phonemes in a word using one or more incorrect graphemes that can represent that phoneme in any position of a word in general English), even after controlling for age, reading level, parental education level, and age at implantation. Apel and Masterson (2015) reported that children with CIs produced more omissions and illegal errors (i.e., unallowable sequences in specific positions based on the constraints in written English such as “mnat”, “lrrp” or “ssat”) than children with typical hearing. Furthermore, when examining the distribution of categorical errors among junctures (i.e., spelling changes that occur when morphemes are combined) and affixes, there were no significant group differences with junctures, but children with CIs were more likely to omit or illegally spell affixes. Taken together, these studies indicate potential deficits in all of the linguistic domains that support spelling among children with CIs.

Comparisons of Hearing Technology and Spelling

Many children with CIs or hearing aids are provided sufficient auditory-linguistic access to utilize spoken language as their primary mode of communication. However, many children with hearing loss receive degraded input due to the effects of sensorineural hearing loss, noise, and reverberation (Delage & Tuller, 2007). Nevertheless, relative to children who are hard of hearing (HH), children with CIs have more profound degrees of hearing loss and thus are more likely to have greater hair cell loss and subsequently poorer integrity of the auditory mechanism. Additionally, children with CIs have less access to robust hearing with their hearing aids in the first year of life prior to cochlear implantation relative to children who are HH (de Kleijn et al., 2018). It is of interest whether differences in early auditory experiences and severity of hearing loss have an effect on literacy domains such as spelling. The one known study comparing the spelling performance of children utilizing different types of technology found no significant between-group differences in the spelling accuracy of adolescents with hearing loss, but children with hearing aids performed better than children with CIs, regardless of whether they received their implant before 42 months or after 42 months (Harris & Terlektsi, 2011). While the results of this study seem to suggest that personal hearing technology has little influence on the quantity of spelling errors, the heterogeneity among the subjects in communication modalities, frequency of device use, and age of identification among the participants confound the results.

Purpose of the Study

Given the limited information regarding spelling among children with CIs, the purpose of this exploratory study was to conduct an in-depth analysis of spelling errors produced by elementary school children with CIs who use spoken language as their primary means of communication. Comparing the spelling performance of children with CIs, children with typical hearing and children who are HH provides greater understanding about the impact of different histories and degrees of auditory

access on spelling performance. This is also the first study to examine spelling in the context of writing samples with the population of children with CIs and compare their performance to peers with typical hearing and peers who are HH. While word dictation tests provide better control for word targets, writing samples provide an ecologically valid assessment of child performance because writing samples mimic the demands of the classroom and everyday life. The first goal was to determine whether there were differences in the spelling accuracy or types of errors between children who were implanted early (e.g., by 24 months) and age-matched peers with typical hearing. The second aim was to determine whether there were differences in spelling accuracy or types of errors between children who were implanted early and age-matched peers with mild to severe hearing loss that utilize hearing aids. The specific research questions were:

- Do children with CIs differ from children with typical hearing in the percentage of total spelling errors or the frequency distribution of categorical spelling errors?
- Do children with CIs differ from children who are HH in the percentage of total spelling errors or the frequency distribution of categorical spelling errors?

Method

Participants

The children with CIs were selected from a larger study ($n = 23$) examining spelling performance and linguistic knowledge of children with CIs ranging in age from 7 years 3 months to 11 years (Quick, 2017). The children with CIs were recruited through audiology clinics, special schools for the deaf, and centers serving children with hearing loss in four states. The children with CIs primarily used spoken English and had at least one CI. The age of identification ranged from 0 to 40 months, and the age of initial implantation ranged from 12 to 83 months. Approximately one-quarter of the children with CIs were reported to have additional disabilities such as ADHD, apraxia, learning disabilities, and neurological disorders. Six of the children came from homes where a second language was spoken in addition to English, including Bosnian ($n = 2$), Hindi, Italian, Punjabi, and Urdu. All of the children attended mainstream classrooms or schools for deaf children that ascribed to an auditory-oral communication philosophy.

Within the larger study of children with CIs ($n = 23$), there was a great deal of heterogeneity among variables that are known to significantly affect language and literacy development, such as age of diagnosis, additional disabilities, and age of implantation. Therefore, children included in the current study were implanted by 24 months and did not have additional disabilities. This maximized between-group homogeneity in the comparisons with children who have typical hearing and children who are HH. The inclusionary criteria resulted in nine children with CIs being included in the present study. Attempts were made to match subjects on age, gender, and maternal education level. Selected demographics of the children with CIs, children with typical hearing, and children who are HH are reported in Table 1.

The children with typical hearing and the children who are HH were selected from a database of an ongoing multi-site longitudinal study, Outcomes of School-Age Children who are Hard of Hearing (OSACHH). The OSACHH database included test information collected from 93 children with typical hearing and 188 children with mild to severe hearing loss who wear hearing

aids. Participants had no significant additional disabilities, and had at least one parent whose primary language was English. While wearing insert earphones or supra-aural headphones, children with typical hearing completed a hearing screening at either 15 or 20 dB HL at octave frequencies from 250–8,000 Hz. All children with typical hearing passed the screening at those levels. Audiometric thresholds for children who are HH were obtained using conventional audiometry or conventional audiometry with video reinforcement and insert earphones or supra-aural headphones.

Measures

The Writing Samples subtest of the Woodcock-Johnson III Tests of Achievement, (WJ-III; Woodcock, McGrew, & Mather, 2001) was administered to all participants. This subtest is designed to measure a child's ability to write words and sentences in response to a prompt and picture cue. For the current study, a secondary language and spelling analysis was conducted on these writing samples.

The POMplexity for Roots and Affixes (Quick & Erickson, 2018) is an informal spelling assessment for examining underlying linguistic strengths and weaknesses that children bring to the task of spelling. Misspelled words are first divided into morphemes. Each morpheme is then separately analyzed three times in order to code for phonological, orthographic and morphological errors.

Procedures

The samples from the Writing Samples subtest of the WJ-III were transcribed and analyzed with the Systematic Analysis of Language Transcripts (SALT; Miller & Iglesias, 2012) software in

order to provide an overall assessment of the linguistic complexity of childrens' writing samples. Utilizing conventional SALT procedures, the following measures were generated: Total Number of T-Units (T-Units; determined by the number of independent clauses and their modifiers), Mean Length of Utterance in Morphemes (MLU-M; average number of words and grammatical morphemes per T-Unit), Subordination Index (SI; ratio of the total number of clauses to the total number of T-Units), Total Number of Words (TNW; total number of words in writing sample), Number of Different Words (NDW; total number of different words in writing sample), and Type Token Ratio (TTR; ratio of the number of different words to the total number of words).

Next, each word in the writing samples was coded as correct, misspelled, or unanalyzable. Unanalyzable data, which were removed from analysis, included illegible words that could not be identified from sentential context, as well as abbreviations and numerals ($n = 15$; 0.8%). Each analyzable word was coded for morphological complexity: monomorphemic (e.g., "jump", "animal"), compound/contracted (e.g., "blindfold", "he's"), inflected (e.g., "walking", "shops"), and derived (e.g., "helpful", "happiness"). In addition, the U-score was determined for each word, which is an indicator of the frequency and dispersion of the word in written English (Zeno, Ivins, Millard, & Duvvuri, 1995). Finally, each misspelled word was analyzed using the POMplexity for Roots and Affixes (Quick & Erickson, 2018).

Scoring

POMplexity for Roots and Affixes

After parsing misspelled words into morphemes, each morpheme was scored as being correct or incorrect (e.g., in "walky" for "walking" the morpheme "walk" is correct and "y" is

Table 1. Selected demographics of participants

Group	CI		HH		TH	
	M (SD)	Min-Max	M (SD)	Min-Max	M (SD)	Min-Max
Selected demographics						
Age	102.9 (14.6)	89–128	103.3 (13.8)	91–128	104.3 (13.0)	93–130
Age of identification	4 (7.2)	0–18	2.3 (6.4)	0–18	—	—
Age of hearing aid fitting	9.17 (6.5)	0.5–20	15.8 (13.1)	4.0–39	—	—
Age of first implantation	18.2 (5.4)	12–24	—	—	—	—
Age of second implantation	31.6 (13.9)	12–51	—	—	—	—
Better ear pure tone average	—	—	47.92 (9.12)	40–67.5	—	—
Additional Demographics						
Gender	n		n		n	
	Male	5		6		6
	Female	4		3		3
Race	Asian	2		0		0
	Black	1		1		1
	Other	1		1		0
	White	5		7		8
Maternal Ed	High school	2		1		1
	Some college	2		2		3
	College	3		4		3
	Graduate	2		2		2
Ed Setting	Mainstream	7		9		9
	School for the deaf	2		0		0
CI Manufacturer	Advanced Bionics	3		—		—
	Cochlear America	5		—		—
	Med-El	1		—		—

Note. CI, cochlear implant; HH, hard of hearing; TH, typical hearing; Ed, education.

incorrect). Then each misspelled morpheme was analyzed three times and assigned a phonological, orthographic, and morphological categorical error. Phonological errors were further categorized based on the type of error: phonologically plausible (i.e., misspelled words that can be pronounced like the target; “werd” for “word”), a single substitution, a single omission, a single addition, or multiple errors. Orthographic errors were categorized as: minor (i.e., spacing, apostrophe or transposition error), having one or more legal vowel errors, one or more legal consonant errors, both vowel and consonant errors, or one or more illegal errors (e.g., “sstop” for “stop”). Finally, morphological errors were categorized as: morphologically plausible (i.e., minor errors demonstrating awareness of the target morpheme; “makeing” for “making”), homophone substitution (e.g., “write” for “right”), morpheme substitution (e.g., “plant” for “planet”), non-morpheme substitution (e.g., “burd” for “bird”), or omission (e.g., “walk” for “walked”). Further details regarding administration and scoring can be found elsewhere (Quick & Erickson, 2018). Appendix A provides examples of phonological, orthographic and morphological errors for both roots and affixes.

Grouping of morphemes for analysis

Morphemes with similar characteristics were grouped into one of three categories: monomorphemic roots, multimorphemic roots, and affixes. Monomorphemic roots included single morpheme words, as well as both morphemes of compound and contracted words. Multimorphemic roots included the roots of both inflected and derived words, and affixes included inflectional affixes, prefixes and suffixes. Words with three morphemes (e.g. teach-er-s, blind-fold-ed) were retained, but only the first two morphemes were coded and included in the analysis, due to low frequency of occurrence ($n = 150$, .06%).

Relative percentage calculations

Spelling errors were standardized in two ways. First, the frequency counts of categorical errors in each morpheme group were standardized by the total number of misspelled morphemes within each morpheme group. This provided a percentage measure of the portion of all errors represented by each type of error. Next, frequency counts of categorical errors in each morpheme group were standardized by the total number of times the participant produced that type of morpheme within the writing sample. This provided a percentage measure of the likelihood of an error when children attempted to write each type of morpheme.

Reliability

Interobserver agreement for SALT measures was calculated for 24% of the samples ($n = 10$) between the first author and two trained undergraduate coders. Interobserver agreement for POMplexity measures was calculated for 35% of the samples ($n = 12$) between the first author and three trained graduate coders. The Krippendorff's alpha test (Hayes & Krippendorff, 2007) was used to estimate interobserver agreement for all measures because this statistical method accounts for both chance agreement and the degree of difference between three or more coders for both ratio and nominal data (Bennett, Taljaard, Olaithe, Brennan-Jones, & Eikelboom, 2017). For each measure, Krippendorff's alpha was computed for the primary researcher and one trained coder, and then the arithmetic mean was manually computed across all researcher-coder pairs. Krippendorff's alpha was high for all SALT measures (T-Units, MLU-M, NDW,

NTW, TTR) ($\alpha = 0.987\text{--}0.999$), with the exception of the subordination index (SI; $\alpha = 0.55$). The low alpha for SI reflects its sensitivity to and dependency on other measures such as T-units and MLU.

Interobserver agreement for the POMplexity measures was first determined by transcribing all words and coding them for agreement with word identification, spelling accuracy, and morphological word type with a mean percentage of agreement of 0.98 (range = 0.97–0.98). After consensus was reached for disagreements, Krippendorff's alpha was calculated for POMplexity, showing high interobserver agreement across all domains (phonology, orthography, morphology) ($\alpha = 0.90\text{--}0.94$, $M = 0.93$). All secondary coders were blind to the hypotheses of the study as well as the hearing status of the children.

Analyses

Statistical analyses were completed using SPSS version 24.0 for Macintosh (IBM Corp, 2016). The categorical data were not normally distributed and included multiple outliers with the potential to bias group comparisons. Rather than exclude data from the analysis that might reflect infrequent but important variations, data from all categorical errors were retained, and Mann-Whitney tests were used for between-group comparisons of rank-ordered categorical data.

As this was an exploratory study, multiple pairwise comparisons of categorical errors were conducted within the linguistic domains of phonology, orthography, and morphology without adjustments. The use of adjustments for multiple comparisons in exploratory studies increases the likelihood of rejecting a potentially significant finding and meaningful result, and therefore shielding it from a more intensive scrutiny in future confirmatory studies (Rothman, 1990). Consequently, results that achieved the 0.05 significance level in the absence of adjustments for multiple testing were preserved. None of those results survived an adjustment for multiple comparisons. Effect sizes were calculated using r as proposed by Cohen (1988).

Results

Descriptive Statistics of Spelling Performance among Children with CIs

The writing samples of children with CIs ($n = 9$) ranged in length from 35 to 289 words ($M = 93.67$), with an average of 89.0% ($\pm 8.1\%$) of each participant's words spelled correctly. The sentences produced by children with CIs were primarily comprised of monomorphemic words (87.2%, $\pm 4.8\%$) and inflected words (10.9%, $\pm 5.1\%$), with very few compound (1.6%, $\pm 1.5\%$) or derived words (0.3%, $\pm 0.7\%$). Most monomorphemic words were spelled correctly (93.8%, $\pm 6.7\%$), while approximately half of the compound words (55.8%, $\pm 46.9\%$), inflected words (60.0%, $\pm 22.8\%$), and derived words (50.0%, $\pm 70.7\%$) were spelled correctly.

As reported in Table 2, there were both similarities and differences in the most frequently occurring categorical errors across the three morpheme groups. In the domain of phonology, phonologically plausible errors occurred most frequently (31.7–40.7%), composing approximately one-third of the errors. Omissions (26.8%) and substitutions (14.8%) represented the second most frequently occurring phonological error type among monomorphemic and multimorphemic roots, respectively. In the domain of orthography, legal vowel or consonant errors were the most frequent type of categorical errors among

monomorphemic roots (29.3%), and legal consonant errors among multimorphemic roots (33.3%). Minor orthographic errors were the most frequent among affixes (14.8%). In the domain of morphology, non-morpheme substitutions composed nearly half of the errors among monomorphemic and multimorphemic roots (44.4–46.3%), while omitted morphemes made up more than one-fifth of the errors among affixes (22.2%).

Before comparing spelling performance between groups, it was necessary to determine group equivalence in lexical and syntactic measures of the writing samples. Group equivalence strengthens conclusions that differences found in spelling can be attributed to spelling rather than overall complexity or quality of the writing samples. As reported in Table 3, children with CIs performed similarly to children with typical hearing and children who are HH for all variables measured in SALT, and none were statistically significant at the 0.05 level.

Comparison of Subset of Children with CIs and Children with Typical Hearing

Independent samples *t*-tests revealed no significant group differences in the percentage of spelling errors of all words between children with CIs ($10.9\% \pm 8.1\%$) and children with typical hearing ($13.0\% \pm 9.7\%$) [$t(16) = 0.492$, $p = 0.629$, $d = 0.24$] or among words of different morphological status. Children with CIs ($12,319 \pm 3,149.7$) selected to write words that were more frequent and dispersed (i.e., higher *U*-score) than children with typical hearing ($9,270 \pm 3,537.1$). Although the difference in *U*-score was not significant [$t(16) = -1.931$, $p = 0.071$, $d = 0.91$], the effect size was very large.

The results of Mann–Whitney *U* tests used to compare the relative percentage of categorical spelling errors among monomorphemic roots within the domains of phonology, orthography and morphology between children with CIs and children with typical

hearing are reported in Table 4. Among monomorphemic roots, children with CIs used a significantly lower percentage of homophone substitutions (3.7%) than children with typical hearing (23.3%), with a large effect size ($r = 0.61$; Rosenthal, 1994).

Children with CIs also had a higher percentage of correctly spelled roots in misspelled multimorphemic words (39.2%) compared to peers with typical hearing (6.2%). The difference was not significant ($p = 0.05$) but again, the effect size was large ($r = 0.50$; Rosenthal, 1994). Among multimorphemic roots, children with CIs had a significantly lower percentage of orthographic legal vowel errors (13.7%) than their peers with typical hearing (47.2%), with a large effect size ($r = 0.60$). Among affixes, there were no significant differences between children with CIs and children with typical hearing in the percentage of any type of categorical error. Children with CI produced a higher percentage of omitted affixes (2.2%) than children with typical hearing (0%), and though the difference was not statistically significant ($p = 0.077$), there was a large effect size ($r = 0.51$). The results of Mann–Whitney *U* tests used to compare the relative percentage of categorical spelling errors among multimorphemic words between children with CIs and children with typical hearing are reported in Table 5. The same set of analyses were conducted on categorical spelling errors relative to the total number of opportunities, with no differences in the results that were statistically significant.

Comparison of Subset of Children with CIs and Children who are HH

To address the second goal of the study, the same sets of analyses were completed comparing children with CIs and age-matched peers who are HH. Children with CIs had a lower percentage of spelling errors ($M = 10.9\%$, $\pm 8.1\%$) than children who are HH (16.4% , $\pm 24.1\%$), but the difference was insignificant [$t(16) = 0.657$, $p = 0.521$, $d = 0.31$]. When examining the average *U*-score of all words, children with CIs chose to write words ($12,319 \pm 3,149.7$)

Table 2. Number and percentage of categorical spelling errors in monomorphemic roots, multimorphemic roots, and affixes among children with cochlear implants

		Monomorphemic roots		Multimorphemic roots		Affixes	
		<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Correct		3	7.3	10	37	15	55.6
Phonology	Plausible	13	31.7	11	40.7	4	14.8
	Substitution	6	14.6	4	14.8	1	3.7
	Omission	11	26.8	1	3.7	0	0
	Addition	4	9.8	0	0	0	0
	Multiple	4	9.8	1	3.7	1	3.7
Orthography	Omitted	—	—	—	—	(6) ^a	(22.2) ^a
	Minor	7	17.1	0	0	4	14.8
	Vowel	12	29.3	4	14.8	1	3.7
	Consonant	12	29.3	9	33.3	0	0
	V & C	3	7.3	4	14.8	1	3.7
Morphology	Illegal	4	5.9	0	0	0	0
	Omitted	—	—	—	—	(6) ^a	(22.2) ^a
	Plausible	6	14.6	1	3.7	3	11.1
	Homophone	2	4.9	1	3.7	2	7.4
	Morpheme	11	26.8	3	11.1	0	0
	Non-morpheme	19	46.3	12	44.4	1	3.7
	Omitted	—	—	—	—	6	22.2

Note. Correct monomorphemic roots = correctly spelled morpheme in a compound word. For monomorphemic and multimorphemic roots, the percentage of correct morphemes and categorical errors within each domain is equal to 100%. ^aFor affixes, omitted morphemes were not scored for phonological or orthographic categorical errors.

that were more frequent and dispersed in written English than children who are HH ($10,458 \pm 1,948$). Although the difference was not significant, there was a large effect size [$t(16) = -1.507$, $p = 0.155$, $d = 0.71$].

Next the relative percentages of categorical spelling errors within the domains of phonology, orthography and morphology were compared between children with CIs and children who are HH using Mann–Whitney U tests. There were no significant differences in the types of categorical spelling errors produced by children with CIs and children who are HH whether examining monomorphemic roots (see Table 6), or multimorphemic roots and affixes (see Table 7). Among affixes, there was one between-group difference that was not significant ($p = 0.139$) but of a large effect size ($r = 0.50$). Children with CIs produced a higher percentage of minor orthographic errors in misspelled multimorphemic words (13.7%) than their peers who are HH (0%). The same set of analyses were conducted on categorical spelling errors relative to the total number of opportunities, with no differences in results.

Discussion

This study sought to examine the linguistic nature of spelling errors among elementary school-age children with CIs who are early-implanted, have no reported additional disabilities, and primarily use a spoken language approach. While there is a need for caution in interpreting these findings due to the small sample

size, we believe that these findings contribute important information about the potential types of spelling errors children with CIs produce that can be used to inform further research in this area.

While children with CIs had a lower percentage of spelling errors than age-matched children with typical hearing or children who are HH, the differences were not significant. These results are consistent with those reported using age-matched peers with typical hearing in a word dictation task that controlled for reading ability ($M = 8.97$; $SD = 1.57$; Hayes et al., 2011); however, the results are in contrast to the results with reading-matched peers with typical hearing on a standardized assessment and graded-level word dictation task ($M = 8.11$; $SD = 1.10$; Apel & Masterson, 2015). The contradictory findings may be an artifact of the assessment context and the difficulty of the targeted words across studies. The standardized and graded-level word lists used by Apel and Masterson may have been more challenging than the experimenter-developed list of Hayes and colleagues.

In addition, the contextualized, sentential writing samples in the current study may have been less challenging because children had some control over the words they chose to write. Although the average U -score of words produced by children with CIs was not significantly lower than peers with typical hearing or who are HH, there was a large effect size suggesting that a larger sample may yield statistically significant differences. Therefore, the comparable spelling performance between children with CIs and the comparison groups may have been influenced by the fact that they chose to write words that are

Table 3. Measures of lexical and syntactical quantity and quality of writing samples

Measure	CI		TH		HH	
	M	(SD)	M	(SD)	M	(SD)
T-Units	17.11	(8.62)	19.44	(10.78)	13.78	(3.49)
MLU Morpheme	5.39	(1.55)	6.56	(2.26)	5.49	(2.29)
Number of Different Words	57.00	(38.78)	78.11	(44.38)	49.00	(20.90)
Number of Total Words	93.67	(80.19)	128.0	(80.27)	70.22	(31.72)
Type Token Ratio	0.65	(0.07)	0.67	(0.13)	0.71	(0.07)
Subordination Index	1.10	(0.19)	0.86	(0.71)	0.94	(1.10)

Note. CI, cochlear implant; TH, typical hearing; HH, hard of hearing.

Table 4. Nonparametric comparisons (Mann–Whitney Z and associated two-tailed asymptotic significance) of categorical spelling errors based on total number of errors in monomorphemic roots between children with cochlear implants and children with typical hearing

Domain	Categorical error	U	CI mean rank/(Mdn)	TH mean rank/(Mdn)	z	p	r
Monomorphemic roots							
Phonology	Correct	37.50	9.17 (0.000)	9.83 (0.125)	−0.291	0.796	0.07
	Plausible	22.00	7.44 (0.333)	11.56 (0.625)	−1.639	0.113	0.39
	Substitution	28.50	8.17 (0.000)	10.83 (0.125)	−1.165	0.297	0.27
	Omission	60.50	11.72 (0.250)	7.28 (0.125)	1.777	0.077	0.42
	Addition	51.00	10.67 (0.000)	8.33 (0.000)	1.273	0.387	0.30
Orthography	Multiple	46.00	10.11 (0.000)	8.89 (0.000)	0.615	0.666	0.14
	Minor	31.00	8.44 (0.000)	10.56 (0.111)	−0.899	0.436	0.21
	Vowel (V)	46.50	10.17 (0.272)	8.83 (0.250)	0.531	0.605	0.13
	Consonant (C)	52.00	10.78 (0.333)	8.22 (0.200)	1.020	0.340	0.24
	V&C	31.50	8.50 (0.000)	10.50 (0.000)	−0.947	0.436	0.22
Morphology	Illegal	40.50	9.50 (0.000)	9.50 (0.000)	0.000	1.00	0
	Plausible	44.00	9.89 (0.000)	9.11 (0.000)	0.368	0.796	0.09
	Homophone	14.00	6.56 (0.000)	12.44 (0.231)	−2.569	0.019*	0.61
	Morpheme	56.00	11.22 (0.250)	7.78 (0.125)	1.384	0.190	0.33
	Non-Morpheme	39.50	9.39 (0.500)	9.61 (0.429)	−0.089	0.931	0.02

Note. *Significant at $p < 0.05$ level; CI, cochlear implant; TH, typical hearing.

Table 5. Nonparametric comparisons (Mann–Whitney Z and associated two-tailed asymptotic significance) of categorical spelling errors based on total number of errors in multimorphemic roots and affixes between children with cochlear implants and children with typical hearing

Domain	Categorical error	U	CI mean rank/ (Mdn)	TH mean rank/(Mdn)	z	p	r
Multimorphemic Roots							
Correct		63.00	12.00 (0.400)	7.00 (0.000)	2.125	0.050	0.50
Phonology	Plausible	27.5	8.06 (0.400)	10.94 (0.600)	−1.160	0.258	0.27
	Substitution	44.00	9.89 (0.000)	9.11 (0.000)	0.391	0.796	0.09
	Omission	28.00	8.11 (0.000)	10.89 (0.000)	−1.397	0.297	0.33
	Addition	36.00	9.00 (0.000)	10.00 (0.000)	−1.00	0.730	0.24
	Multiple	41.00	9.56 (0.000)	9.44 (0.000)	0.081	1.00	0.02
Orthography	Minor	36.00	9.00 (0.000)	10.00 (0.000)	−1.00	0.730	0.24
	Vowel (V)	12.00	6.33 (0.000)	12.67 (0.500)	−2.563	0.011*	0.60
	Consonant (C)	43.50	9.83 (0.333)	9.17 (0.250)	0.273	0.796	0.06
	V&C	44.00	9.89 (0.000)	9.11 (0.000)	0.394	0.796	0.09
	Illegal	36.00	9.00 (0.000)	10.00 (0.000)	−1.0	0.730	0.24
Morphology	Plausible	35.00	8.89 (0.000)	10.11 (0.000)	−0.748	0.666	0.18
	Homophone	45.00	10.00 (0.000)	9.00 (0.000)	1.00	0.730	0.24
	Morpheme	39.00	9.33 (0.000)	9.67 (0.000)	−0.182	0.931	0.04
	Non-Morpheme	26.00	7.89 (0.500)	11.11 (0.800)	−1.303	0.222	0.31
Correct		21.50	7.39 (0.600)	11.61 (0.833)	−1.713	0.094	0.40
Phonology	Plausible	39.50	9.39 (0.000)	9.61 (0.000)	−0.101	0.931	0.02
	Substitution	40.50	9.5 (0.000)	9.5 (0.000)	0.000	1.00	0
	Omission	40.50	9.5 (0.000)	9.5 (0.000)	0.000	1.00	0
	Addition	40.50	9.5 (0.000)	9.5 (0.000)	0.000	1.00	0
	Multiple	45.00	10.0 (0.000)	9.0 (0.000)	1.00	0.730	0.24
Orthography	Minor	51.5	10.72 (0.000)	8.28 (0.000)	1.166	0.340	0.27
	Vowel (V)	35.5	8.94 (0.000)	10.06 (0.000)	−0.680	0.666	0.16
	Consonant (C)	40.50	9.5 (0.000)	9.5 (0.000)	0.000	1.00	0
	V&C	40.00	9.44 (0.000)	9.56 (0.000)	−0.081	1.00	0.02
	Illegal	40.50	9.5 (0.000)	9.5 (0.000)	0.000	1.00	0
Morphology	Plausible	54.00	11.00 (0.000)	8.00 (0.000)	1.837	0.258	0.43
	Homophone	41.50	9.61 (0.000)	9.39 (0.000)	0.122	0.931	0.03
	Morpheme	31.50	8.50 (0.000)	10.50 (0.000)	−1.455	0.436	0.34
	Non-Morpheme	40.00	9.44 (0.000)	9.56 (0.000)	−0.081	1.00	0.02
	Omitted	63.00	11.78 (0.200)	7.22 (0.000)	2.158	0.077	0.51

Note. *Significant at $p < 0.05$ level. CI, cochlear implant; TH, typical hearing.

more frequent and dispersed in written language. As poor spellers are likely to restrict their writing to words they can spell confidently (Kohnen, Nickels, & Castles, 2009), spelling difficulties among participants may be partially masked by the use of writing samples as an assessment context. Finally, although the mothers in this sample represented a wide range of educational backgrounds, it is important to note that the sample was biased toward higher levels of education, which is associated with better language outcomes among children with CIs (Szagun & Stumper, 2012).

Despite similar performance in spelling accuracy, children with CIs differed from children with typical hearing in the types of spelling errors they produced, with some large effect sizes. These differences suggested linguistic strengths in both morphology and orthography among children with CIs when results were standardized on the total number of errors. For example, children with CIs produced a lower percentage of homophone substitutions than children with typical hearing in misspelled monomorphemic roots. This may be an artifact of their less specified access to phonological representations and reliance on uncompromised visuo-orthographic skills to map word meaning with morphographic sequences. In other words, children with CIs may be less apt to recognize that “right” and “write” are homophones. As a result, they may be more attentive to using

orthographic knowledge to pair meaning with the written form, thus reducing the likelihood of homophone substitution errors.

Children with CIs also produced fewer legal vowel errors in multimorphemic roots than children with typical hearing. This may be due to the increased orthographic saliency of vowels, as only six primary vowels (23% of letters in English) account for approximately 39% of the characters comprising words (Mayzner & Tresselt, 1965). Given the robust visuo-orthographic skills of children with CIs, they may capitalize on the audio-visual saliency of this limited set of highly frequent graphemes, supporting orthographic memory of their use in morphemes, and thus fewer vowel errors.

There were two additional differences between children with CIs and peers with typical hearing that were not significant but had a large effect size. The combination of a small sample and large effect sizes suggests the possibility of additional true differences if the study included a larger number of participants. First, children with CIs produced a higher percentage of correctly spelled roots than affixes among misspelled multimorphemic words than children with typical hearing. In comparison to roots, affixes are comprised of phonemes that are higher in frequency and lower in intensity (e.g. /s/, /z/, /t/), and when in medial sentence positions they are often less salient due to shorter durations (Hsieh, Leonard, & Swanson, 1999), making

Table 6 Nonparametric comparisons (Mann–Whitney Z and associated two-tailed asymptotic significance) of categorical spelling errors based on total number of errors in monomorphemic roots between children with cochlear implants and children who are hard of hearing

Domain	Categorical error	U	CI mean rank/(Mdn)	HH mean rank/(Mdn)	z	p	r
Monomorphemic Roots							
Correct		40.50	9.50 (0.000)	8.44 (0.000)	0.538	0.673	0.13
Phonology	Plausible	26.00	7.89 (0.333)	10.25 (0.625)	−0.972	0.370	0.23
	Substitution	28.00	8.11 (0.000)	10.00 (0.125)	−0.901	0.481	0.21
	Omission	48.00	10.33 (0.250)	7.50 (0.125)	1.166	0.277	0.27
	Addition	48.00	10.33 (0.000)	7.50 (0.125)	1.736	0.277	0.41
	Multiple	36.00	9.00 (0.000)	8.89 (0.000)	0	1.00	0
Orthography	Minor	41.00	9.56 (0.000)	8.38 (0.250)	0.598	0.673	0.14
	Vowel (V)	29.00	8.22 (0.272)	9.88 (0.250)	−0.679	0.541	0.16
	Consonant (C)	56.00	11.22 (0.333)	6.50 (0.200)	1.952	0.051	0.46
	V&C	25.00	7.78 (0.000)	10.38 (0.000)	−1.239	0.321	0.29
	Illegal	37.00	9.11 (0.000)	8.88 (0.000)	0.129	1.00	0.03
Morphology	Plausible	48.00	10.33 (0.000)	7.50 (0.000)	1.736	0.277	0.41
	Homophone	26.50	7.94 (0.000)	10.19 (0.231)	−1.230	0.370	0.29
	Morpheme	40.00	9.44 (0.250)	8.50 (0.125)	0.390	0.743	0.09
	Non-morpheme	30.50	8.39 (0.500)	9.69 (0.428)	−0.535	0.606	0.13

Note. *Significant at $p < .05$ level. CI = cochlear implant. HH = hard of hearing.

Table 7. Nonparametric comparisons (Mann–Whitney Z and associated two-tailed asymptotic significance) of categorical spelling errors based on total number of errors in multimorphemic roots and affixes between children with cochlear implants and children with who are hard of hearing

Domain	Categorical error	U	CI mean rank/(Mdn)	HH mean rank/(Mdn)	z	p	r
Multimorphemic Roots							
Correct		48.00	10.33 (0.400)	7.50 (0.000)	1.223	0.277	0.30
Phonology	Plausible	28.00	9.67 (0.400)	8.25 (0.167)	0.592	0.606	0.14
	Substitution	30.50	8.39 (0.000)	9.69 (0.167)	−0.595	0.606	0.14
	Omission	35.00	8.89 (0.000)	10.44 (0.000)	−0.172	0.963	0.04
	Addition	36.00	9.00 (0.000)	9.00 (0.000)	0	1.0	0
	Multiple	26.00	7.89 (0.000)	10.25 (0.000)	−1.299	0.370	0.32
Orthography	Minor	27.00	8.00 (0.000)	10.12 (0.000)	−1.546	0.423	0.37
	Vowel (V)	47.00	10.22 (0.000)	7.62 (0.000)	1.316	0.321	0.32
	Consonant (C)	35.50	8.94 (0.333)	9.06 (0.333)	−0.049	0.963	0.01
	V&C	26.00	7.89 (0.000)	10.25 (0.250)	−1.087	0.370	0.26
	Illegal	36.00	9.00 (0.000)	8.00 (0.000)	0	1.0	0
Morphology	Plausible	25.00	7.78 (0.000)	10.38 (0.000)	−1.422	0.321	0.34
	Homophone	40.00	9.44 (0.000)	8.50 (0.000)	0.943	0.743	0.23
	Morpheme	44.00	9.89 (0.000)	8.00 (0.000)	1.374	0.481	0.33
	Non-Morpheme	31.50	8.50 (0.500)	9.56 (0.500)	−0.443	0.673	0.11
Correct		22.50	7.50 (0.600)	10.69 (0.833)	−1.333	0.200	0.32
Phonology	Plausible	41.00	9.56 (0.000)	8.38 (0.000)	0.599	0.673	0.15
	Substitution	40.00	9.44 (0.000)	8.50 (0.000)	0.943	0.743	0.23
	Omission	36.00	9.0 (0.000)	9.0 (0.000)	0	1.0	0
	Addition	36.00	9.0 (0.000)	9.0 (0.000)	0	1.0	0
	Multiple	40.00	9.44 (0.000)	8.50 (0.000)	0.943	0.743	0.23
Orthography	Minor	52.00	10.78 (0.000)	7.00 (0.000)	2.071	0.139	0.50
	Vowel (V)	30.00	8.33 (0.000)	9.75 (0.000)	−0.869	0.606	0.21
	Consonant (C)	36.00	9.0 (0.000)	9.0 (0.000)	0	1.0	0
	V&C	40.00	9.44 (0.000)	8.50 (0.000)	0.943	0.743	0.23
	Illegal	36.00	9.0 (0.000)	9.0 (0.000)	0	1.0	0
Morphology	Plausible	43.00	9.78 (0.000)	8.12 (0.000)	0.906	0.541	0.22
	Homophone	44.00	9.89 (0.000)	8.00 (0.000)	1.374	0.481	0.33
	Morpheme	36.00	9.0 (0.000)	9.0 (0.000)	0	1.0	0
	Non-Morpheme	35.00	8.89 (0.000)	9.12 (0.000)	−0.172	0.963	0.04
	Omitted	45.00	10.00 (0.200)	7.88 (0.000)	0.973	0.423	0.24

Note. *Significant at $p < 0.05$ level. CI, cochlear implant; HH, hard of hearing.

them more difficult to hear. As a result, children with CIs may find affixes more difficult to read, store as mental graphemic representations (i.e., orthographic representation) and spell

correctly than acoustically more salient roots. Second, children with CIs produced more omitted affixes than their peers with typical hearing. These results suggest that difficulties children

with CIs are known to have with bound morphemes in spoken language (Halle & Duchesne, 2015) may also be present in written language for at least some children with CIs, and therefore may warrant targeted intervention.

This is the first known study to compare the spelling of early-implanted children with CIs to children with mild to severe hearing loss. Despite differences associated with various technologies and auditory histories, children with CIs demonstrated performance that was indistinguishable from children with mild to severe hearing loss in this study, which has also been reported when comparing children with CIs to children who wear hearing aids with more profound degrees of hearing loss (Harris & Terlektsi, 2011). There was only one insignificant difference of large effect size between children with CIs and children who are HH. Children with CIs produced a higher percentage of minor orthographic errors among affixes than their peers who are HH. Further investigation is needed to determine whether this is a true difference or artifact of this study.

Group differences between children with different technologies may be masked by insufficient sample size and the lack of control for potentially confounding factors such as age of identification, age of hearing aid fitting, and frequency of technology use. It is also possible that equivalent performance reflects more similarities than differences in auditory-linguistic access. Although children who are HH have the potential to experience optimal access following initial hearing aid fitting within the first months of life, Walker et al. (2013) found that many of these children do not achieve full-time use until 18–24 months of age. In addition, Walker et al. found that children with milder hearing loss were reported to have less consistent hearing aid use than their peers with more severe hearing loss. In contrast, it is possible that families of children with more profound hearing loss may be more motivated to pursue earlier consistent hearing aid use because trials are strongly encouraged by most implant teams prior to establishing CI candidacy. Therefore, it may be that children with CIs experience less optimal access to the speech spectrum but more consistent hearing aid use early on relative to children who are HH. In addition, children with CIs may benefit from optimal auditory access with their implants if they are implanted just prior to, or around the same time as children who are HH benefit from optimal auditory access due to more consistent hearing aid use. Thus, despite the divergent early auditory experiences and acoustic signals experienced by these two populations, they may experience similar uptake in language domains that inform spelling, leading to more similarities than differences in orthographic development.

Implications

The lack of significant difference in spelling accuracy between early-implanted children with CIs and their peers with typical hearing was unexpected, but very encouraging. In the absence of other disabilities, profound hearing loss may no longer need to be associated with many of the deleterious effects on literacy skills such as spelling, particularly when children are able to benefit from earlier implantation of newer implant technology and a spoken language approach. This is at least the case for the children in the current study who were implanted with CIs early and do not have other disabilities. However, it is important to note that these demographics may not be representative of the greater population of children with CIs, as a significant number of recruited children from a larger study had later ages of implantation, additional disabilities, or both.

Second, group differences in spelling profiles between children with and without hearing loss suggest that early-implanted children with CIs appear to bring different linguistic strengths and weaknesses to the spelling of less familiar or unknown words, as compared to same-age peers with typical hearing. When examining the sample of children with CIs, only one-third of their errors in monomorphemic roots were considered phonologically plausible, which is significantly less than the 55% reported among a larger sample of children with typical hearing and children who are HH (Quick, 2017). These results suggest that at least some children with CIs may have difficulty with phonological coding during spelling. Therefore, children with CIs, particularly those who struggle with spelling, may benefit from spelling instruction that targets this area of weakness through phonological awareness tasks or direct instruction in sound to grapheme encoding for linkages of identified difficulty. Vulnerability in the development of phonological awareness also highlights the importance of ensuring optimal and consistent auditory access as early as possible, in order to support the development of phonological representations required for both oral and written language development.

Although most professionals today would discount earlier claims of a “deafness advantage” in spelling due to visual memory strengths (Templin, 1948), the distribution of categorical spelling errors in orthography and morphology among the subset of children with CIs who were implanted early suggests that these children capitalize upon relative strengths in visual processing. Therefore, children with CIs who struggle with spelling may benefit from instruction that highlights these forms of linguistic awareness and takes advantage of relative strengths in visuo-orthographic skills. Repertoire Theory postulates that children with typical hearing use different forms of linguistic knowledge to varying degrees across time (Masterson & Apel, 2013). Therefore, it is even possible that children with CIs who struggle with phonological awareness would benefit from instruction that strengthens orthographic or morphological knowledge, as these domains are able to harness the power of vision for probabilistic learning and storage of mental graphemic representations.

While the information provided by word dictation tasks for spelling is not to be discounted, the results of this study suggest that important information about spelling achievement can also be obtained from contextualized writing tasks. This context of formative assessment provides information about children’s ability to spell within the multilayered subsystems of writing such as planning, organization, cohesion, vocabulary, grammar, reviewing, and monitoring (Mackenzie, Scull, & Munsie, 2013). Furthermore, given the ever-increasing demands on the time of speech-language pathologists, evaluating spelling within writing samples provides an efficient means for assessing and monitoring skills, as well as evaluating intervention through pre- and post-assessment, as clinicians collaborate with classroom teachers to support spelling achievement.

Limitations and Future Directions

The results of this study must be interpreted with caution due to several limitations. The sample size was limited as a result of recruitment challenges associated with low-incidence populations. Furthermore, nearly two-thirds of the children with CIs who were recruited for the larger study were implanted after the age of two, had additional disabilities, or both. Therefore, the exclusion of children who are late-implanted or with additional disabilities for group comparisons with children who

have typical hearing or who are HH may have resulted in inflated spelling performance among this group. Increasing the number of participants in future studies could not only reveal true significant differences between the groups, but allow for more heterogeneity in the sample.

This study is also limited by the matching procedures. Participants were not matched for reading or language level, and including a control group matched in one or both of these domains would strengthen conclusions about spelling abilities while controlling for potential covariates. In comparing groups of children who utilize different hearing technologies, future investigations should consider controlling for age of identification, audibility, and consistency of technology use. No data was collected on spelling instruction in educational settings, which could also impact child performance. Finally, while the use of participant generated writing samples provides an ecologically valid measure of spelling achievement, it also introduces significant heterogeneity in the sampling context. The variation in sample length and spelling contexts complicates the results, and there may be less stability in the SALT scores, spelling accuracy and POMplexity scores of children who submitted small samples. Using a combination of both writing samples and word dictation tasks would likely provide a more thorough and comprehensive understanding of spelling ability in this population. Nevertheless, this study contributed important information about the spelling of children with CIs, particularly by identifying qualitative differences in spelling errors that should provoke further investigation in both assessment and intervention.

Conclusion

The present study suggests that at least some children with CIs demonstrate equivalent spelling accuracy in contextualized, sentential writing tasks to that of children with typical hearing. This study adds to the existing literature by providing a more nuanced analysis of spelling errors produced by children with CIs. Differences in the distribution of categorical spelling errors suggest that children with CIs may differ in the degree to which they utilize various linguistic domains that support spelling relative to children with typical hearing, while being more similar in the strategies they use to spell words relative to children who are HH. For those children with CIs who struggle with spelling, these findings may provide an important first step in identifying strengths and weaknesses in the linguistic foundations of spelling that may be used to inform the development of targeted spelling interventions.

Supplementary Data

Supplementary data is available at *Journal of Deaf Studies and Deaf Education* online.

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Conflict of interest

No conflicts of interest were reported.

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