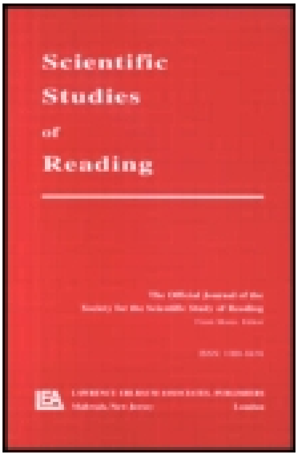

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Spelling of Deaf Children Who Use Cochlear Implants

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Spelling of Deaf Children Who Use Cochlear Implants

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The spellings of 39 profoundly deaf users of cochlear implants, aged 6 to 12 years, were compared with those of 39 hearing peers. When controlled for age and reading ability, the error rates of the 2 groups were not significantly different. Both groups evinced phonological spelling strategies, performing better on words with more typical sound–spelling correspondences and often making misspellings that were phonologically plausible. However, the magnitude of these phonological effects was smaller for the deaf children than for hearing children of comparable reading and spelling ability. Deaf children with cochlear implants made the same low proportion of transposition errors as hearing children. The findings indicate that deaf children do not rely primarily on visual memorization strategies, as suggested by previous studies. However, deaf children with cochlear implants use phonological spelling strategies to a lesser degree than hearing peers.

For people who have early hearing loss, achieving average literacy levels by adulthood is a difficult task. The median reading comprehension skills for deaf 17-year-olds in the United States is at a fourth-grade (9-year-old) level, a delay of about 8 years (Holt, 1993; Traxler, 2000). Deaf children's spelling is also poorer than that of hearing children (Allman, 2002; Burden & Campbell, 1994; Gates & Chase, 1926; Harris & Moreno, 2004; Sutcliffe, Dowker, & Campbell, 1999; Watson, 2002). Even in this age of Twitter and texting, errors in written spelling can lead to negative perceptions about a writer's abilities (Figueredo & Varnhagen, 2005; Kreiner, Schnakenberg, Green, Costello, & McClin, 2002; Varnhagen, 2000), and poor literacy skills are linked to later economic and employment success (e.g., Kutner et al., 2007). Thus, it is important to study

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spelling skills, particularly those of deaf children, who may have limited educational and employment opportunities if their literacy development is significantly delayed.

Spelling is fundamentally a transcription of spoken language, and current theories consider the acquisition of sound-to-spelling mappings to be critical for spelling success (Ehri, 1997). Given this, it is not surprising that people who do not have access to spoken language have difficulty linking words to spellings. Hearing spellers take advantage of sound-to-spelling mappings: They perform better on words with typical spellings—where each sound is represented by one of its most common spellings—than on words with atypical spellings (Leybaert & Alegria, 1995; Treiman, 1993; Waters, Bruck, & Seidenberg, 1985), and they often make phonologically plausible errors, using letters that are legal spellings for the same sound in other words (Leybaert & Alegria, 1995; Treiman, 1993; Waters et al., 1985). Because phoneme–grapheme knowledge is a critical component for successful acquisition of spelling skills in hearing children, it is important to investigate how deaf children's spelling skills might benefit from knowledge of sound–spelling relationships that they may acquire through advanced listening devices, such as cochlear implants.

With cochlear implantation, profoundly deaf children have the opportunity to hear spoken language. Although the implant does not deliver the exact equivalent of natural speech, it may make it easier for deaf children to learn mappings between sounds and spellings. Studies have shown that many children with cochlear implants achieve reading levels that are comparable to hearing children of the same age (e.g., Geers, 2003; Geers, Tobey, Moog, & Brenner, 2008). However, spelling has not been adequately investigated in this rapidly growing population. To determine whether cochlear implants have an effect on deaf children's spelling, we compared oral deaf children with implants to hearing peers and asked the following questions: Do implanted children spell as well as hearing children? When they make an error, is it of the same nature as hearing children's?

Prior research on spelling in deaf children has focused on deaf children without cochlear implants, and those studies are discussed later in this introduction. A few spelling studies included a few implanted children but did not analyze their data separately from those of children who used either hearing aids or no device. To our knowledge, only one study exclusively examined spelling of children with cochlear implants. Watson (2002) looked at eight children who received their implants prior to age 5. There was no comparison group of hearing children, and the author did not report the primary communication method of the deaf children with implants. Watson divided errors into visual (e.g., *maicg* for *magic*, *wrok* for *work*) and phonological (e.g., *casl* for *castle*, *dirdy* for *dirty*) categories. She reported that all eight of the implanted children made visual errors and that six used some phonological strategies. However, she did not report the proportion of visual and phonologically plausible errors, and she provided no additional analyses of the data other than listing examples of spelling errors from each child. In addition, Watson acknowledged that the error categories were quite vaguely defined. Accordingly, the results from this study must be interpreted with caution.

In the current study, we wanted to examine several properties of spelling in children with cochlear implants. We looked to the literature of past studies of spelling in deaf children *without* cochlear implants. (In this review of past research, the unqualified term *deaf children* is used whenever the study did not report whether the participants used cochlear implants. In most such cases, the reasonable assumption is that the children did not use them.) These studies examined error rates, evidence for phonological strategies, and evidence for visual memorization strategies. As mentioned earlier, deaf children make more errors than hearing children of the same age. They are as accurate as hearing children of the same reading age (Burden & Campbell, 1994; Gates & Chase, 1926; Harris & Moreno, 2004; Kyle & Harris, 2006), but the strategies that they use to achieve this level of performance may differ from those used by hearing children.

The evidence for phonological strategies is somewhat conflicting. Most studies have found that deaf children spell words with more typical spellings more accurately than words with atypical spellings (Burden & Campbell, 1994; Kyle & Harris, 2006; Leybaert & Alegria, 1995; Leybaert, 2000; Leybaert & Lechat, 2001; Sutcliffe et al., 1999), but Dodd (1980) did not find this typicality effect. One might expect that deaf children would be less influenced by typicality than hearing children. Burden and Campbell (1994) found this to be the case, but Kyle and Harris (2006) did not. Another diagnostic of a phonological strategy is errors that are based on how the word sounds. Phonologically plausible errors, such as *pennsul* for *pencil*, represent all the phonemes of a word but use some letter correspondences that are orthographically correct only in other words. These could be considered good errors, in that they are likely to be interpreted correctly by the reader. The spelling errors of deaf children are sometimes phonologically plausible, but they make phonologically plausible errors far less frequently than hearing children (Aaron, Keetay, Boyd, Palmatier, & Wacks, 1998; Dodd, 1980; Harris & Moreno, 2004; Hoemann, Andrews, Florian, Hoemann, & Jensema, 1976; Leybaert, 2000; Leybaert & Alegria, 1995; Leybaert & Lechat, 2001; Sutcliffe et al., 1999).

Evidence for deaf children's use of visual memorization strategies toward spelling is more robust. Deaf children show a frequency effect, in that they spell more frequent words more accurately than less frequent words (Burden & Campbell, 1994; Leybaert, 2000; Sutcliffe et al., 1999). Hearing children show a frequency effect also (Burden & Campbell, 1994; Lété, Peereman, & Fayol, 2008; Leybaert, 2000; Treiman, 1993), but there are mixed findings as to whether it is more or less strong than the frequency effect found in deaf children. Burden and Campbell (1994) found that deaf children were more sensitive to frequency than hearing children matched for reading ability, but Leybaert (2000) found that deaf children who received intensive cued-speech instruction were less affected by frequency than hearing children.[1] Deaf children also make letter transposition errors that are phonologically implausible, such as *wrom* for *worm* (Hoemann et al., 1976; Padden, 1993). Hearing children occasionally make these types of errors also, but several studies have reported that deaf children make transposition errors far more often than hearing peers (Aaron et al., 1998; Leybaert, 2000; Leybaert & Alegria, 1995). For example, Leybaert and Alegria (1995) reported that 7% of deaf children's errors were transpositions as compared to 1% of hearing children's.

One concern with the aforementioned studies is that most failed to report the type of hearing device used, if any (Aaron et al., 1998; Burden & Campbell, 1994; Dodd, 1980; Harris & Moreno, 2004; Hoemann et al., 1976; Johnson, Padak, & Barton, 1994; Leybaert & Alegria, 1995; Padden, 1993; Sutcliffe et al., 1999). As mentioned earlier, if any of the participants did use cochlear implants, their data were not analyzed separately (Kyle & Harris, 2006; Leybaert & Lechat, 2001). Also, several of the studies did not focus specifically on children who used oral language. Instead, many of the children used sign language, finger spelling, or cued speech (Harris & Moreno, 2004; Hoemann et al., 1976; Leybaert, 2000; Padden, 1993; Sutcliffe et al., 1999), all of which can affect how the children learn and relate to the alphabet and pronunciation.

Another concern with previous studies is in the poor definitions of properties such as typicality and phonological plausibility. All previous studies of deaf children categorized words as being either typical or atypical (using the terms *regular* or *irregular*). However, words are rarely wholly typical or atypical. Phonological errors were defined as misspellings that could be pronounced as the target words, but none of the studies reported any reference material or guidelines that were used to determine how the misspelling could be pronounced. One study simply stated that the experimenter deemed an error plausible if it could be recognized by sounding it out (Aaron et al., 1998). There are problems with this approach, because phonemes can be represented by a variety of graphemes and not all may be obvious possibilities to an adult reader. One study (Harris & Moreno, 2004) did report using a second rater to confirm whether misspellings were phonologically acceptable. Overall, however, the definition of sound-based errors in these studies was vague at best.

A final concern is that all of the aforementioned studies of spelling in deaf children reported statistical analyses only by subjects; none investigated whether the results were consistent across items. By-subjects analyses collapse results across items, which eliminates the possibility of analyzing variance due to item

[1] Cued speech is a communication method whereby a person uses spoken language while making hand gestures near the face to disambiguate certain phonemes that are difficult to lip read.

characteristics. One might think that the addition of a traditional by-items analysis (in which results are collapsed across subjects) would solve this problem, but this is not necessarily the case. As described in more detail next, we used an alternative statistical analysis—mixed modeling—which has been shown to be a more robust tool for investigating potential sources of variance than separate by-subjects and by-items analyses (Baayen, 2004; Jaeger, 2008; Locker, Hoffman, & Bovaird, 2007).

The current study aims to address the methodological concerns just cited and to expand the quantitative study of spelling of deaf children to those who use oral language and cochlear implants. We compared deaf implanted children to hearing peers on three properties: error rate, use of phonological strategies, and use of visual memorization strategies. Children spelled words in a picture spelling task, and these spellings were analyzed for spelling accuracy, factors such as typicality that may contribute to accuracy, phonological plausibility of errors, and rate of transposition errors.

In addition, we asked whether the age at which children receive their implant makes a difference in spelling accuracy and plausibility of errors. To our knowledge, no studies to date have investigated age at implant effects on spelling. Investigation of this factor is necessary because results in the literature are mixed on whether age at implantation affects performance on other aspects of literacy (Connor & Zwolan, 2004; Geers, 2003).

METHOD

Participants

Thirty-nine deaf children with cochlear implants (20 male) contributed data. Table 1 describes additional characteristics of the participants. All children had received a cochlear implant by the age of 8 years, with all but 1 child receiving the implant by age 6 years. The children had no known additional physical disabilities, and English was the primary language spoken in the home. At some point in their early education, the children all attended private special schools for deaf children. These schools all ascribed to an auditory-oral communication philosophy, with intensive instruction in speech and language skills. At the time of testing, the children were either still attending the special deaf schools or in mainstream classrooms in public or private schools. All of the children in this study used spoken language as their primary means of communication. One child had a parent with a moderate-to-severe hearing loss, but oral communication was used exclusively in the home. Two of the children were adopted, and it could not be determined whether their biological parents had hearing loss. All of the other implanted children's parents had normal hearing.

TABLE 1
Participant Characteristics

	Group	*M*	*SD*	*Minimum*	*Maximum*
Age (years)	Deaf	8.97	1.57	6.25	12.17
	Hearing	8.69	1.45	6.42	11.83
Parent education (years)	Deaf	16.5	2.6	12	21
	Hearing	17.4	2.0	12	21
Reading score	Deaf	102.5	14.2	69	132
	Hearing	114.9	13.2	73	145
Age at implantation (years)	Deaf	3.02	1.26	1.50	8.00

Note. Mean difference between groups was significant only for reading comprehension, $t(76) = 2.19$, $p = .03$.

The control group included 39 hearing children (20 male) who were chosen from a larger group of 53 in order to match the deaf children on age, parent education, and sex. The hearing children had no known additional disabilities and spoke English as their primary language. Some of the children were recruited using a database of families who indicated interest in reading and language research. Some were siblings of the deaf, implanted participants, and some were recruited from private schools.

Materials

Parent questionnaire. Parents of all children were asked to complete a questionnaire about family and child characteristics. Parents of deaf children with cochlear implants were also asked questions pertaining to their child's hearing loss and implant.

Picture spelling task. Traditional spelling measures often involve an experimenter reading a word list and a child spelling what he heard the experimenter say. For deaf children, even those with cochlear implants, there are obvious problems with this approach, and therefore a picture spelling task was designed. Eighty words that were likely to be familiar to a young deaf child were selected, based on the judgment of experienced teachers of the deaf. The words, which are listed in the appendix, varied in length and orthographic complexity. Each word was represented by a drawing or a photograph, sometimes on a sticker, but mostly printed directly in the booklet. Children were asked first to name the pictured item and then to spell the name on a line that appeared under the picture. The children were encouraged to guess the name of any item they did not immediately identify. The experimenter attempted to avoid naming the item for the child, using questions to lead the child to the correct name. Only if the child became frustrated did the experimenter name the item. The experimenter avoided naming the item so that the child could not use the experimenter's speech model to guide his or her pronunciation, which may have affected the way the child spelled the word.

The 80 target words were grouped into four booklets of 20 target items each. This was done to make the task less daunting for the participants. In each booklet, two additional pictures were presented, the spellings of which were already written by the experimenter. These eight filler items were considered to be motivating and fun, as many children were relieved to see that the experimenter "helped" them by doing a few items.

Reading comprehension test. The Reading Comprehension subtest of the Peabody Individual Achievement Test–Revised (PIAT–R; Markwardt, 1998) was administered to all participants. Most of the deaf children had recently received this test at school ($n = 30$) and thus were not given the test again as a part of this study. The Reading Comprehension subtest requires that the child read a sentence and then choose from among four pictures the image that best matches the meaning of the sentence. The PIAT–R provides grade equivalent and standardized scores, the latter of which were used in this study. According to the testing manual, Kuder-Richardson reliability coefficients for the reading comprehension subtest ranged from .94 to .97 for children ages 6 to 12 years.

Procedure

Testing took place in a laboratory at Washington University in St. Louis, at the child's school, or in the child's home. All of the tasks were completed in either one or two sessions, with most of the children finishing all tasks in one session lasting approximately 1 hr. During the picture spelling task, an experimenter transcribed the child's picture naming, and an audio recording was made. Parents completed the questionnaire either prior to or during the child's testing session.

Statistical Analyses of Spelling Accuracy and Phonological Plausibility of Errors

For the accuracy and plausibility analyses, we used mixed modeling, sometimes called cross-classified modeling. We chose this statistical approach because it allowed us to investigate the effects of differing characteristics of the words, children, and the trials in a single analysis. Mixed modeling is more flexible and powerful than traditional by-subjects or by-items analyses (Baayen, 2004; Jaeger, 2008; Locker et al., 2007). In a single model, subjects and items can be treated as random effects and missing data are not problematic. In addition, full maximum likelihood estimation is a more flexible method of estimating models than ordinary least squares estimation. In all, mixed modeling determines sources of variability more accurately than traditional by-subjects and by-items analyses of variance.

The accuracy and plausibility analyses were at the trial level, and three types of predictors were included: characteristics of the word, child, and trial. We used the software package lme4 (Bates, 2009), selecting a generalized mixed-effects model with a logit link function and treating the children and the words as random effects. All nonbinary variables were centered at their grand means.

The following word characteristics were included as fixed-effect predictors (see Table 2):

- *frequency*: the natural log of frequency per million, weighted by dispersion of the word throughout different texts, in the corpus of Zeno, Ivenz, Millard, and Duvvuri (1995).
- *phonemes*: the natural log of the number of phonemes.
- *typicality*: we wrote a program to compute how typical the spelling of each phoneme in the stimulus was, by determining what proportion of the time the phoneme is spelled in general English vocabulary in the same way it is spelled in the stimulus word: the higher the number, the more typical the spelling. We chose the figure for the least typical of the phoneme spellings to characterize the word as a whole, because we expected that the most difficult sound-to-letter correspondence would have the greatest impact on spelling accuracy. Proportions were computed typewise (weighting each word in the corpus equally, regardless of how often it occurs) over all words for which Zeno et al. (1995) broke down frequency counts by grade level. Examples of typicality values are .765 for *stamp* and .002 for *scissors*.
- *compound status*: whether the stimulus was a compound of simpler words, like *rainbow* ($N = 8$)

TABLE 2
Characteristics of Target Words in the Picture Spelling Task

	M	*SD*	*Minimum*	*Maximum*
Frequency per million	50.02	93.39	1	579
Phonemes	4.45	1.51	2	9
Typicality	.13	.18	0	.88

Note. $N = 80$, of which 8 were compound words.

These characteristics of the children were also included as fixed effects (Table 1):

- *sex*
- *age* at testing
- *parent education* level: the higher of the parents' education level, in years
- *reading score* on the PIAT–R test
- *age at implantation* of the cochlear device (only in analyses limited to deaf children)
- *hearing status*: whether the child was hearing or deaf (in combined analyses over all children)

Trial-level fixed effect characteristics were included to control for any effects of the child not knowing the pictured item or not being able to pronounce the item's name correctly:

- *misidentification*: whether the child had to be told what word the picture represented. Because children with cochlear implants have significantly smaller vocabularies on average than hearing children (see Hayes, Geers, Treiman, & Moog, 2009), we wanted to control for the possibility that the deaf children with implants might have more difficulty naming the items than hearing peers, even though we did choose items that should have been known to all children of this age range.
- *mispronunciation*: whether the child added, omitted, or transposed phonemes, or substituted one phoneme for another. Subphonemic articulation idiosyncrasies were not counted as errors. On a sample of 602 trials, two transcribers agreed on 97% of the phonemes. We included information about pronunciation in the analysis because implanted children's speech production was potentially a factor in how they spelled words.

RESULTS

Spelling Accuracy

The purpose of this analysis was to determine the error rate of deaf children with cochlear implants as compared to that of hearing peers and to examine the factors that contribute to whether a child spells a word correctly.

On average, deaf children with cochlear implants spelled 55% ($SD = 27\%$) of words correctly as compared to 66% ($SD = 26\%$) for hearing children. The implanted children failed to guess the intended word in 3% of our trials, three times as often as the hearing children. The deaf group mispronounced 25% of the trials, compared to 1% for the hearing group.

Our first mixed-effects analysis included both deaf and hearing children, using accuracy as the binary response variable, with interactions between all word characteristics and hearing status. The model that included fixed effects accounted for significantly more variation than the model containing only the random effects of child and word ($p < .001$). Hearing status itself was not a significant predictor of accuracy. The only significant interaction with the child's hearing status was with typicality: hearing children, more so than deaf children with implants, were more accurate in spelling words with typical spellings ($\beta = 1.869$, $SE = 0.531$, $p < .001$). To permit a closer contrast between the two groups, we also ran analyses separately for the deaf children with cochlear implants and for the hearing children. The results of these separate analyses are presented in Table 3, which also shows the zero-order correlations between accuracy and each of the predictors.

TABLE 3
Mixed Model Analyses of Spelling Accuracy for Deaf and Hearing Children

Predictor	*Group*	*Correlation*[a]	*Coefficient*	*SE*
Frequency	Deaf	.189	0.459**	0.141
	Hearing	.148	0.514***	0.132
Phonemes	Deaf	−.258	−4.201***	0.635
	Hearing	−.224	−3.988***	0.593
Typicality	Deaf	.125	3.778***	0.920
	Hearing	.166	5.733***	0.919
Compound	Deaf	−.036	2.627***	0.652
	Hearing	−.010	2.997***	0.610
Female sex	Deaf	.019	0.344	0.538
	Hearing	.192	1.020*	0.445
Parent education	Deaf	.061	−0.073	0.109
	Hearing	.168	−0.190	0.124
Age	Deaf	.281	1.564***	0.229
	Hearing	.386	1.499***	0.192
Reading	Deaf	.089	0.128***	0.025
	Hearing	.182	0.075***	0.017
Implantation age	Deaf	.081	−0.159	0.230
Misidentified	Deaf	−.136	−0.920	0.503
	Hearing	−.058	−0.737	0.630
Mispronounced	Deaf	−.148	−0.362*	0.146
	Hearing	−.083	−0.817	0.539

Note. This table presents the results of two separate analyses, one for each of the subject groups.
[a]Zero-order product-moment correlation of the predictor with accuracy.
*$p < .05$. **$p < .01$. ***$p < .001$.

Child characteristics. Greater age and reading comprehension both had a positive effect on accuracy. Hearing girls made fewer mistakes than hearing boys, but sex was not a significant factor among deaf children. There were no significant effects of parental education levels or of the age at which deaf children received their cochlear implant.

Word characteristics. The more typical, frequent, and short a word was, the more accurately children spelled it. Also, compound words were easier to spell than comparable noncompound words.

Trial characteristics. Failing to identify a word from its picture or failing to pronounce the word correctly correlated weakly with error rates but in general had no significant effect once factors such as word length and frequency were taken into account in the mixed-models analysis. However, mispronunciation did significantly predict an inaccurate trial for deaf children with cochlear implants, who mispronounced 25% of all trials.

Phonological Plausibility of Spelling Errors

Of interest in this analysis was whether the errors made by deaf children with cochlear implants were phonologically plausible—indicating use of phonological knowledge during spelling—and how the implanted children's performance in this respect compares with hearing peers. We also asked whether age at implantation was a predictor of phonological plausibility of errors. Although studies have addressed the question of phonological misspellings in deaf children without cochlear implants, they did not clearly define what they considered to be a phonological misspelling. We adapted the conceptualization of phonological plausibility used in a study of hearing children by Ellefson, Treiman, and Kessler (2009): A spelling was considered plausible if each of the phonemes in the word was spelled, in correct left-to-right sequence, by a letter that aligns with that phoneme in any position in any of the words in the aforementioned subset of Zeno et al. (1995). For example, *gosst* would be considered a plausible misspelling of *ghost*, but not *xths* or *ghots*.

We ran the same sort of mixed-model analyses as previously described under the Spelling Accuracy section, except that we considered only the 2,458 trials with spelling errors (1,400 deaf, 1,058 hearing), and used plausibility as the binary response variable. Results of the separate analyses for deaf and hearing children are presented in Table 4. Results of a combined analysis, not shown here, were very similar. Most notably, the combined analyses showed that hearing status, as predictor, was significant ($\beta = 1.512$, $SE = 0.334$, $p < .001$): the errors of hearing children were more plausible phonologically than those of deaf children with

TABLE 4
Mixed Model Analyses of Phonological Plausibility of Errors of Deaf and Hearing Children

Predictor	*Group*	*Correlation*[a]	*Coefficient*	*SE*
Frequency	Deaf	.078	0.059	0.150
	Hearing	.018	−0.168	0.142
Phonemes	Deaf	−.296	−4.050***	0.671
	Hearing	−.204	−2.737***	0.661
Typicality	Deaf	−.194	−2.345*	1.001
	Hearing	−.192	−2.201*	1.017
Compound	Deaf	−.148	0.409	0.659
	Hearing	−.134	−0.278	0.599
Female sex	Deaf	−.071	−0.165	0.472
	Hearing	.000	−0.355	0.377
Parent education	Deaf	.022	−0.105	0.096
	Hearing	.048	0.026	0.103
Age	Deaf	.094	0.834***	0.225
	Hearing	.037	0.387	0.205
Reading	Deaf	.049	0.070**	0.024
	Hearing	.112	0.035*	0.014
Implantation age	Deaf	.013	−0.219	0.209
Misidentified	Deaf	−.050	0.129	0.366
	Hearing	−.021	−0.347	0.609
Mispronounced	Deaf	−.107	−0.424*	0.186
	Hearing	−.091	−1.404**	0.466

Note. Table presents the results of two separate analyses, one for each of the subject groups.
[a]Zero-order product-moment correlation of the predictor with plausibility.
*$p < .05$. **$p < .01$. ***$p < .001$.

cochlear implants. No interactions of hearing status with any word property were significant.

Child characteristics. Hearing children made a higher proportion of plausible errors (75% of all errors) than deaf children with cochlear implants (44%). Older children and those with higher reading comprehension produced errors that were significantly more plausible. Sex, parental education levels, and age of implantation had no significant effect on plausibility rates.

Word characteristics. Shorter words had more plausible misspellings. Also, the more typical the word's standard spelling is, the less plausible the error was. This outcome, which may seem unexpected at first glance, means that spelling out a word by sounds is more likely to lead to a correct answer if the spelling is typical, as in *stamp*, but more likely to lead to an error, and thus be counted here as a plausible error, if the target spelling is atypical, as in *thumb*, which might be spelled *thum*. Both deaf and hearing children were affected comparably by these word characteristics. Word frequency and its status as a compound word had no effect on plausibility of errors.

Trial characteristics. Deaf and hearing children who mispronounced the word made a lower proportion of phonologically plausible errors. Misidentification did not significantly affect plausibility.

Transpositions

In the following analysis, we calculated the proportion of transpositions (e.g., *wrom* for *worm*) made by deaf and hearing children in order to determine whether deaf children with cochlear implants make transpositions significantly more often than hearing children. Because some transpositions are phonologically plausible errors (e.g., *jepe* for *jeep*, *castel* for *castle*), we analyzed only spelling errors that were phonologically implausible according to the definition described earlier in the phonological plausibility analysis. Thirty-six deaf children and 31 hearing children made a total of 1,052 implausible spelling errors.

Not surprisingly, deaf children with cochlear implants made more implausible errors than hearing children (789 vs. 263). They also made more transposition errors (38 vs. 12). However, the proportion of implausible errors that were transpositions was only 5% for the deaf group. This proportion of these so-called visual errors was the same for hearing children, and there was no significant difference between the proportion of errors made by the two groups, $t(1050) = -1.67$, $p = .87$.

DISCUSSION

Children must acquire good spelling skills to be good readers and successful participants in school. Children with profound hearing loss are at a distinct disadvantage compared with hearing children, because access to spoken language helps children learn the correct sequence of phonemes in words, and phonemes are the basis of alphabetic spelling. Previous studies of deaf children have found that they are poorer spellers than hearing age-mates. The current study investigated the spelling skills of deaf children with cochlear implants—a device that provides deaf children with access to spoken language. We found that, after controlling for other child attributes such as age and reading comprehension level, deaf children with cochlear implants were not significantly poorer spellers than hearing children. This held true even when we removed all hearing status interactions and trial characteristics from the combined analysis of deaf and hearing children: Hearing status in itself still did not predict accuracy.

We were also interested in how the characteristics of the words being spelled affected children's spelling accuracy and whether deaf children with cochlear implants were affected by these word-level factors differently than hearing children. The results showed that the same word-level factors that facilitated hearing children's spelling accuracy also helped deaf children with cochlear implants. These factors were frequency, length, whether the word was a compound word, and typicality. The frequency effect was not surprising, because that is a robust finding in past studies of both deaf and hearing children (Burden & Campbell, 1994; Lété et al., 2008; Leybaert, 2000; Sutcliffe et al., 1999; Treiman, 1993). The length effect, although not a new finding about hearing children (Treiman, 1993), has not been previously reported for deaf children's spellings. However, to our knowledge, no study has investigated whether compound words are easier for deaf or hearing children to spell than other words. The results of the mixed-model analysis, which shows that compound words are easier than other words, seems to contradict the zero-order correlation reported earlier, which shows that compound words are harder to spell than other words. The difference is that the mixed-model analysis controls for other word properties, including the greater word length that compound words tend to have. Consider, for example, the stimulus *backpack*. As an eight-letter word, it is harder to spell than a shorter word like *black*, which is the simple fact picked up by the zero-order correlation. But compared to eight-letter words that are not compounds, such as *elephant*, the compound word *backpack* is relatively easy to spell, because it is made up of two shorter and easier words. Previous studies have found that hearing children use familiar smaller units when constructing the spellings of inflected and derived words (Deacon & Bryant, 2006).

One of the central findings of the analyses of spelling accuracy concerned the typicality effect. Both deaf and hearing children displayed the typicality effect, spelling words with more typical sound–spelling correspondences better than atypically spelled words. Hearing children were more sensitive to typicality than deaf children with cochlear implants, supporting the finding of Burden and Campbell (1994), the only other study in the deaf spelling literature to show different effects between deaf and hearing children. Although typicality effects have been found in previous studies of both deaf and hearing children (Burden & Campbell, 1994; Kyle & Harris, 2006; Leybaert, 2000; Leybaert & Alegria, 1995; Leybaert & Lechat, 2001; Sutcliffe et al., 1999; Treiman, 1993; Waters et al., 1985), the typicality measure used in our analysis was unique for studies of deaf and hearing children's spelling. Our measure allowed for spellings to be considered more or less regular on a continuous scale and was based on a corpus of words found in children's reading materials (Zeno et al., 1995). A similar measure was developed by Spencer (2007), but it was based on a smaller corpus of adult-level words.

Although determining degree of spelling accuracy was an important first step in describing deaf, cochlear-implanted children's spelling skills, we were also interested in whether these children's errors are similar in nature to those of hearing children, and whether these errors provide evidence of phonological or visual memorization strategies. Given the importance of phonology in learning to spell (e.g., Ehri, 1997), it was especially important to determine whether the errors of deaf children with cochlear implants reveal use of a phonological strategy.

Deaf children with implants were less likely than hearing children to make spelling errors based on the sounds in the word, after controlling for age, reading comprehension, and other personal attributes. This finding supports our interpretation of the Typicality × Hearing Status interaction in the accuracy analysis: Deaf children with cochlear implants did not use phonological knowledge in spelling to the same extent as hearing children. Previous studies found that deaf children made far fewer phonological types of errors than hearing peers (Aaron et al., 1998; Dodd, 1980; Harris & Moreno, 2004; Hoemann et al., 1976; Leybaert, 2000; Leybaert & Alegria, 1995; Leybaert & Lechat, 2001; Sutcliffe et al., 1999), but these studies neither focused on users of cochlear implants nor used a quantitative definition of what constitutes a plausible error.

The current study found that children with implants did not make many transposition errors and in fact made the same proportion as hearing children. Previous studies of deaf children without implants have found that deaf children make a higher proportion of transposition errors than hearing children (Aaron et al., 1998; Leybaert, 2000; Leybaert & Alegria, 1995), which suggests the use of a visual memorization strategy in spelling. Our finding suggests that cochlear implants may provide enough phonological information for deaf children so that they can rely less on visual memorization strategies than their deaf counterparts without implants. However, given the results of the accuracy and plausibility analyses, deaf children with implants do not use phonology as successfully as hearing children.

We investigated whether age at implantation affected spelling accuracy and plausibility of spelling errors, given that many previous studies have described robust age-at-implant effects on speech perception (e.g., Zwolan et al., 2004), speech production (e.g., Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006), and language development (e.g., Geers, Moog, Biedenstein, Brenner, & Hayes, 2009). However, the findings in the literature on reading and age at implant effects are mixed, and so it is not entirely surprising that we failed to find an age at implant effect on spelling in the current study. Connor and Zwolan (2004) reported that younger is better than older for reading comprehension, but their participants were older on average at implantation ($M = 6.78$ years) and had a greater range in age of implantation (younger than 5 years to 14 years old) than participants in the current study. In contrast, Geers (2003) found no age-at-implantation effect on reading skills, and her population was similar to ours (M

age at implant = 3.42 years, range = 1.67–5.25 years). It is possible that receiving an implant very late in childhood has negative consequences for reading development as compared to receiving an implant at a relatively early age. However, as long as the child receives the implant relatively early, there may not necessarily be any additional benefit to reading and spelling development of very early implantation. Clearly, additional research on children with varying ages at implant must be done to investigate this important theoretical and practical question.

Limitations and Future Directions

This study investigated spelling skills in a specific group of deaf children: those who wear cochlear implants. It would have been interesting to compare this population not only to hearing children but also to a third group: children who are profoundly deaf and who do *not* wear cochlear implants. However, the latter group would have been extremely difficult to recruit. With universal newborn hearing screening and increased access to cochlear implantation at very young ages (younger than 12 months old in some cases), cochlear implants are the devices of choice for many hearing parents of young children with profound hearing loss. Thus, it would have been quite difficult to find profoundly deaf children who use spoken language and who do not wear cochlear implants as a comparison group in this study.

Future studies of deaf children could address some of the topics not covered in the current study, such as whether different types of cochlear implants and speech processing software are associated with different types of spelling errors, whether type of communication mode affects spelling skills, whether bilateral cochlear implantation has any impact on spelling skills compared to a single implant, and whether these results hold up in written languages other than English.

Another line of inquiry in studies of hearing or deaf children could address phonological plausibility and typicality using context-sensitive measures. The measures used in the current study were context free, in that plausible spelling choices for each phoneme were generated with no regard to the context in which the phoneme occurred. However, previous studies have indicated that children do pay attention to some types of context, even as young as kindergarten age (Cassar & Treiman, 1997). We used context-free measures in the current study because they constitute an easily definable baseline that gives children maximum credit for their mistakes. Because no previous studies of deaf spelling had included such quantitative measures of plausibility and typicality, we felt that it was best to start with a context-free approach and address the use of context in a future study.

This study contributed new information about the spelling skills of deaf children with cochlear implants. We believe it was a good first step, but additional work is necessary to understand how cochlear implants allow young deaf children to acquire phonological strategies for use in reading and spelling.

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APPENDIX

Stimuli for Picture Spelling Task

alligator, backpack, balloon, black, blue, boy, bread, brown, carrot, castle, chair, cheese, cloud, computer, cookie, cracker, dinosaur, dress, elephant, faucet, fish, flag, flower, fork, ghost, giraffe, glue, green, hamburger, jeep, kangaroo, knife, ladder, leaf, milk, motorcycle, mouse, nose, pants, pencil, pie, pink, pizza, popcorn, purple, purse, queen, rainbow, ring, scarf, school, scissors, seal, shell, shoe, shoulder, skirt, skunk, slide, snail, snowman, spider, stamp, star, strawberry, swing, sword, thumb, toaster, tooth, tractor, treasure, turtle, umbrella, watermelon, whale, white, witch, worm, yellow