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Research Article

The Role of Sentence Position, Allomorph, and Morpheme Type on Accurate Use of s-Related Morphemes by Children Who Are Hard of Hearing

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Purpose: Production accuracy of s-related morphemes was examined in 3-year-olds with mild-to-severe hearing loss, focusing on perceptibility, articulation, and input frequency.

Method: Morphemes with /s/, /z/, and /ɪz/ as allomorphs (plural, possessive, third-person singular –s, and auxiliary and copula "is") were analyzed from language samples gathered from 51 children (ages: 2;10 [years;months] to 3;8) who are hard of hearing (HH), all of whom used amplification. Articulation was assessed via the Goldman-Fristoe Test of Articulation–Second Edition, and monomorphemic word final /s/ and /z/ production. Hearing was measured via better ear pure tone average, unaided Speech Intelligibility Index, and aided sensation level of speech at 4 kHz.

Results: Unlike results reported for children with normal hearing, the group of children who are HH correctly produced the /ɪz/ allomorph more than /s/ and /z/ allomorphs. Relative accuracy levels for morphemes and sentence positions paralleled those of children with normal hearing. The 4-kHz sensation level scores (but not the better ear pure tone average or Speech Intelligibility Index), the Goldman-Fristoe Test of Articulation–Second Edition, and word final s/z use all predicted accuracy.

Conclusions: Both better hearing and higher articulation scores are associated with improved morpheme production, and better aided audibility in the high frequencies and word final production of s/z are particularly critical for morpheme acquisition in children who are HH.

Children with mild through moderately severe hearing loss (HL) have been shown to have difficulty with the acquisition of grammatical morphology and syntax (Koehlinger, Owen Van Horne, & Moeller, 2013; McGuckian & Henry, 2007). However, the profile of grammatical use in children who are hard of hearing (HH) has not yet been carefully described. Furthermore, it is necessary to examine outcomes for this group separately from those of children with severe–profound HL who utilize cochlear implants given the differences in their auditory experiences. Because children who are HH and use hearing aids do not receive the same quality of input as children with normal hearing (NH), one might hypothesize that they would have particular difficulty with grammatical morphology. Some data tend to support this hypothesis (Koehlinger et al., 2013; McGuckian & Henry, 2007), but other studies have shown that, as a group, children who are HH perform similarly to age-matched control groups (e.g., Norbury, Bishop, & Briscoe, 2001).

The current study aimed to describe the usage patterns observed for a set of morphemes that are likely to be difficult to hear because they are realized as /s/, /z/, or /ɪz/, that is, third-person singular –s, plural –s, copula and auxiliary "is," and possessive –s. We sought to understand what factors influence use in children who are HH by examining characteristics of the morphemes that are known to influence accuracy, such as morpheme type, allomorph type, and sentence position, and by examining child characteristics, such as audibility and articulation skills. Each of these child characteristics was examined in multiple ways to determine which would best capture the variance in morpheme use.

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By examining these utterance and child characteristics in relation to ostensibly similar morphemes, we may contribute to understanding the role of perceptibility and input on learning grammatical morphology.

Morpheme and Child Characteristics That Influence Acquisition in Typical Children

Allomorphic variation is one aspect of morphology that has been shown to influence acquisition. Phonetic variants of morphemes are called *allomorphs*. The allomorphs associated with –s related morphemes (i.e., third-person singular –s, plural –s, possessive –s, and forms of copula and auxiliary "is") are all phonologically conditioned (Berko, 1958). When the inflection follows a voiceless sound, the morpheme is realized as an /s/ (e.g., *books, stumps, the cat's happy*); following a voiced sound, the morpheme is realized as a /z/ (e.g., *toys, roars, goes, the dog's running*). When the stem-final sound is an alveolar or alvelopatalal fricative or affricate, the morpheme is produced as the full syllable /ɪz/ (e.g., *witches, squishes, kisses, the princess is smiling*).

Berko (1958) tested the ability of young children with NH to apply these –s related inflectional markers to novel words. She observed that overall accuracy increased with age and that children more accurately formed novel plurals with the /s/ or /z/ allomorph as opposed to the syllabic /ɪz/ allomorph. This pattern of results was attributed to the fact that /s/ and /z/ allomorphs were more common in the input than /ɪz/. Input frequency has also been argued to influence the order of acquisition of different morpheme types (e.g., plural *–s* is five times more common than third-person singular *–s*; see Hsieh, Leonard, & Swanson, 1999), although other factors have also been considered (e.g., articulatory difficulty; see Mealings, Cox, & Demuth, 2013).

Sentence position has also been shown to affect the use of grammatical markers. Hsieh et al. (1999) found that inflectional markers are longer in duration when located in sentence final position than when located sentence medially and thus are easier to hear. Certain morpheme types also tend to occur in certain sentence positions because of the nature of English syntax. For instance, the plural –s inflection is not only more common overall but also is located sentence finally more often than the third-person singular inflection, amplifying the input differences (Hsieh et al., 1999). Sundara, Demuth, and Kuhl (2011) confirmed that children are sensitive to these duration differences via a grammaticality judgment task using a preferential looking paradigm. Children aged 22 and 27 months listened to sets of grammatical (*He runs now, She sleeps*) and ungrammatical (*He run now, She sleep*) sentences that differed only in the presence of the third-person singular morpheme. When the morpheme was located sentence finally, both groups were able to distinguish between grammatical and ungrammatical sentences. However, when the morpheme was located sentence medially, such a distinction could not be made by either group of children.

Although Hsieh et al. (1999) attributed the sentence position differences to problems with perceptibility, others have attributed accuracy differences to articulatory complexity. Consonant clusters always result from the addition of the /s/ allomorph (e.g., *likes*) and regularly occur when /z/ (e.g., *hides*) is added to a stem as well if the word ends in a consonant. Consonant clusters are not formed when /z/ is appended to a vowel (e.g., *plays*) or when the syllabic allomorph, /ɪz/, is used (e.g., *watches*). Because of the distribution of word final phonemes, which are also known as *codas*, the syllabic allomorph, /ɪz/, is the least commonly used allomorph and the /z/ allomorph is the most common. The role of articulatory complexity has been examined by comparing production of different morphemes realized as singletons and consonant clusters in medial and final utterance positions. Song, Sundara, and Demuth (2009) demonstrated that typically developing children who have NH (mean age = 2;2 [years;months]) produced the third-person singular marker more accurately when it was located in a phonologically simple coda context (e.g., *goes*) as opposed to a complex coda context (e.g., *kicks*), suggesting that simpler articulatory contexts improve production. Unlike the third-person singular results, word final consonant clusters did not affect production of plurals by 2-year-old children who are NH. Plurals were affected by sentence position, however, with greater accuracy observed sentence finally (Theodore, Demuth, & Shattuck-Hufnagel, 2011). Turning to the syllabic allomorph alone, greater difficulty was observed for production of plurals in sentence medial position than in sentence final position. This is arguably because young children have less time to plan and execute the morpheme and 2-year-olds are not yet proficient at this task (Mealings et al., 2013). Likewise, possessives realized as clusters were likely to be reduced to a single phoneme when produced by typical 2-year-olds and were marked through lengthening to ease the articulatory task and preserve the morphological information (Mealings & Demuth, 2014). Thus, we see that morpheme type, sentence position, and allomorph may all interact to influence production accuracy in young children who have NH.

For children with NH, developing articulation skills are also implicated in morphological production. Word final /s/ and /z/ develop gradually in these children. In their most recent textbook, Bernthal, Bankson, and Flipson (2013) compiled 10 studies of age of acquisition of English consonants into a single table. The phoneme /s/ is listed as acquired as early as 3;0 (the earliest age group studied in Dodd, Holm, Hua, & Crosbie, 2003; Prather & Hedrick, 1975; and Smit, Hand, Freilinger, Bernthal, & Bird, 1990) and as late as 5;0 in boys (Smit et al., 1990). Similarly, acquisition of /z/ ranges from age 3;0 (Dodd et al., 2003; Prather & Hedrick, 1975) to age 7;0+ (Chirlian &Sharpley, 1982; Templin, 1957). These differences are attributed to the criteria for producing an adultlike /s/ or /z/ (e.g., is a dentalized /s/ accepted?), the loss of front teeth, and the complexity of the words used to elicit the target sounds. Investigation of word final clusters is much less common. Nonetheless, this suggests a high degree of variability in the acquisition of /s/ and /z/, two sounds that may influence children's ability to produce the target morphemes.

Morpheme and Child Characteristics That Influence Acquisition in Children With HL

Grammatical morphology use by children with HL. Previous research on grammatical morphology use has included late-identified children with varying degrees of HL (e.g., moderate to profound) and has found a general lag in phonological and grammatical development (Dodd, Woodhouse, & McIntosh, 1992; Elfenbein, Hardin-Jones, & Davis, 1994). However, these results may not generalize to children with milder degrees of HL or to children who are identified and have received hearing aids early in life, which is the current standard of care (Joint Committee on Infant Hearing, 2007).

More recent work has focused on children who are HH. For instance, McGuckian and Henry (2007) studied the use of 10 grammatical morphemes by 10 children (mean age = 7;4) with moderate HL and a younger mean length of utterance (MLU)–matched control group (mean age = 3;2) with NH. Children who were HH produced the grammatical markers possessive –s and plural –s less often than the younger control group, but they produced irregular past tense, articles, and progressive –ing more often. Given the 3- to 4-year age gap, this does not indicate normal grammatical morpheme use, but it does suggest that the phonemes involved in realizing the morpheme influence use. Koehlinger et al. (2013) examined finite verb morphology use by 3- and 6-year-old children with HL between 20 and 79 dB HL as well as children with NH of the same age. At both ages, the children with NH were more accurate in their use of verb-related morphemes than those who were HH. However, the particular allomorph used has the potential to influence the perceptibility of these forms in the input, and the use of a composite measure may have obscured differences associated with morpheme type, allomorph, and sentence position.

Articulation abilities in children who are HH. Children who are HH also have difficulty with articulation of speech sounds relevant for producing morphemes, including /s/ and /z/. Gordon (1987) examined consonant production in 37 mainstreamed school-aged students with moderate to profound degrees of HL. She found that children with average hearing levels less than 80 dB HL made fewer consonantal errors on a sentence production task than those with hearing levels greater than 80 dB HL. However, for both groups, fricative and affricate errors were the most common types. Elfenbein et al. (1994) measured speech production skills on the Fisher-Logemann Test of Articulation Competence (Fisher & Logemann, 1971) in 40 school-aged students with moderate to severe HL. The results again showed that the most common error types involved were fricatives and affricates.

More recent studies have supported the finding that fricative production continues to be particularly challenging for children who are HH. For instance, Moeller et al. (2010) followed four late-identified children with a moderate to severe HL. Fricative errors were more common than any other type of speech production error with the exception of one subject (S2) whose fricative errors were as common as errors with other phonemes. Three out of four children omitted postvocalic /s/ and /z/ sounds at 4 years of age, and two still had difficulty at age 5. Moeller et al. (2007) followed 12 early-identified toddlers who were HH longitudinally and found them to be delayed compared to age-matched peers with NH in spontaneous production of fricatives in babble and early words. McGowan, Nittrouer, and Chenausky (2008) examined the spontaneous vocalizations of ten 12-month-old early-identified infants with HL (i.e., >50 dB HL) compared to 10 infants with NH. Using acoustic analysis methods, they found early evidence of differences between the groups in fricative production. Collectively, these results suggest the possibility that limited or inconsistent perceptual access to fricatives affects articulation skills, although data on children with mild-moderate losses are limited.

As mentioned previously, many morphemes in English are realized as word final fricatives and clusters. Traditionally, within the specific language impairment (SLI) literature, children have been screened for articulation difficulties in order to ensure that language, rather than speech, is being assessed (Goffman & Leonard, 2000; Rice & Wexler, 2001). This is less common in the literature on HH, partially due to a sense that screening children for articulation may lead to inclusion of the least severely affected children and unintentionally minimize differences between groups of HH and NH. Nonetheless, difficulty with articulation may cascade into difficulties with grammatical morphology. Consider the child, S2, who presented with persistent articulation difficulties across all phonemes (Moeller et al., 2010). She was also the last to develop verb tense marking and continued to make morpheme omissions through 84 months of age. The other three subjects presented with age-appropriate grammatical development at much earlier ages and showed faster resolution of articulation difficulties.

Audibility and input frequency in children who are HH. Recent studies have indicated that the limited bandwidth of hearing aids affects children's perception of fricatives such as /s/ and /z/ and that audibility must be accounted for to understand acquisition patterns. Stelmachowicz, Pittman, Hoover, and Lewis (2002) examined whether children who are HH perceive regular plural endings produced as an /s/ or /z/ and irregular plurals forms that change the stem of the word by asking children to point to pictures depicting a singular referent or a plural referent. Children who were HH were better able to identify the correct target item when it was an irregular rather than a regular plural. Performance also improved when the target words were presented in a man's voice with peak energy around 4 kHz as compared to a woman's voice with peak energy around 6 kHz. Taken together, these findings suggest that morphemes realized as /s/ and /z/ are difficult to hear for children who are HH. This may be attributable to the effects of restricted hearing aid bandwidth, the fundamental frequency of adult and child voices in the environment, and ambient noise or distance from the speaker. Thus, children who are HH may not reliably perceive grammatical morphemes, even when properly fitted with hearing aids.

McGuckian and Henry (2007) argued that reductions in how often morphemes are perceived in the input have an influence on grammatical morpheme production by children who are HH. Perceiving a morpheme may be affected by the child's access to certain aspects of the speech stream, to how often and where that morpheme occurs in English, and to environmental aspects, such as speaker fundamental frequency, noise, reverberation, and distance from the speaker. In children with NH, production of grammatical morphemes is highly correlated with the frequency of production in child-directed speech (Theakston & Lieven, 2008). McGuckian and Henry (2007), following Larsen-Freeman and Long (1991), argued that children acquiring English from parents who are themselves learning English as a second language (ESL) receive inconsistent input and show altered morphological acquisition. They claimed that children who are HH also are influenced by inconsistent input, albeit for different reasons than their ESL counterparts who have NH. When children who are HH fail to perceive a morpheme, it is as if their parents had never produced the morpheme in that context, reducing the input frequency of that morpheme or allomorph. This altered input functions much like the agrammatical input that children of ESL learners receive. They supported this hypothesis with their finding that the order of acquisition of morphemes is highly correlated between children who are HH and children of ESL learners.

Thus, one might predict different patterns of use of the –s allomorphs for children who are HH than what is observed in children with NH because of the former group's limited ability to hear high-frequency sounds like /s/ and /z/. Specifically, they might be more accurate with the production of the syllabic /ɪz/ allomorph because the inclusion of a vowel in the morpheme makes it more likely to be in the audible range. This allows children who are HH to receive more consistent input for /ɪz/, despite the fact that the syllabic allomorph is less common in the input in general and more likely to be in error in children with NH.

Articulation skills, in particular use of word final /s/ and /z/, may also affect children who are HH (Moeller et al., 2010). There is good evidence that children with NH, like adults, change their production of morphemes to accommodate production challenges, reducing consonant clusters, lengthening the final fricative, and shortening the morpheme in sentence medial position. Similar effects may be observed in the group of children who are HH. Finally, this group may be particularly influenced by changes in morpheme perceptibility due to sentence position given that shortened morphemes may be especially hard for them to hear.

Research Questions and Hypotheses

Children who are HH have difficulties with the perception (Bow, Blamey, Paatsch, & Sarant, 2004; Stelmachowicz, Pittman, Hoover & Lewis, 2001, 2002) and production of /s/ and /z/ as speech sounds (Elfenbein et al., 1994; Moeller et al., 2010) and as grammatical morphemes (Koehlinger et al., 2013; McGuckian & Henry, 2007). Production of grammatical markers is related to frequency, that is, how common the grammatical marker is in the input, and perceptibility, which is linked to its position within a sentence (Hsieh et al., 1999; Song et al., 2009; Sundara et al., 2011). Work with typical children has shown that more frequent allomorphs are more accurately produced (Berko, 1958), despite the fact that the more frequent allomorphs are less perceptible, calling into question the role of perceptibility. What is frequent hinges critically on what is perceptible. Thus a corpus analysis does not directly address this question. Instead the answer must be inferred from children's performance. We were interested in determining how articulation skills, sentence position, perceptibility, and input frequency influence grammatical morpheme acquisition in children with mild-to-severe HL. Thus, we asked the following questions, using productions and omissions of possessive, plural, third-person singular –s, and contracted and uncontracted forms of "is" from spontaneous language samples as data.

1. Does allomorph type influence grammatical accuracy in children who are HH? We predicted that the allomorph that is most accessible in the input would be most accurately produced. Unlike children with NH, who tend to produce /s/ and /z/ allomorphs most accurately (Berko, 1958), we predicted that children who are HH, as a group, would be more likely to produce the syllabic allomorph /ɪz/, rather than the briefer allomorphs /s/ and /z/.
2. Does sentence position influence grammatical accuracy in children who are HH? We predicted that children who are HH, like children with NH, would show greater accuracy when the grammatical marker was located sentence finally than when it was in sentence medial position because the morpheme would be easier to perceive at the end of the utterance. It should be noted that, given the structure of the English language, certain morphemes may distribute differently across different sentence positions.
3. To what extent does perceptual access influence morphological acquisition? Children who are HH do not all have the same hearing profile and access to audible speech. Thus, we predicted that hearing acuity and audibility of speech would influence morphological accuracy. We especially predicted that auditory access to high-frequency sounds would modulate the results of the allomorph and sentence position analyses described above.
4. To what extent does articulation skill influence morphological acquisition? We also predicted that articulation skill would influence morphological accuracy. We predicted that use of word final –s and –z would be more influential than global articulation skills and that both morphological accuracy and articulation skill would be influenced by the degree of HL, particularly high-frequency aided audibility in the child.

Method

Subjects

Children were selected from a larger pool of 115 three-year-olds who were HH and participated in the Outcomes for Children with Hearing Loss project. The Outcomes for Children with Hearing Loss protocol and recruitment approach was described in Holte et al. (2012). All children included here had persistent, bilateral HL in the mild through severe range, had no other known significant language or learning disorders (for additional subject data, including recruitment information, see Koehlinger et al., 2013), and used spoken English as the primary language of communication in the home. All of the children wore personal hearing aids (48 binaural air conduction, two monaural air conduction, one bone conduction). One of the children with a monaural air conduction fitting had asymmetric HL, and the poorer ear was judged to be nonaidable.

Children were selected because (a) the child had a transcribed conversational language sample with at least 40 utterances; (b) the language sample contained a minimum of four contexts for morphemes realized as /s/, /z/, or /ɪz/; (c) the child had participated in a screening for ability to use /s/ and /z/ word finally; and (d) the child had complete articulation testing and audiometric data (see below). Four children met all other requirements but were excluded because of limited information about the ability to use word final s/z. Following these criteria, 51 three-year-olds (age range: 2;10–3;8) who were HH were retained for analysis. All but two children retained for analysis had data from the Comprehensive Assessment of Spoken Language core 3–4 (Carrow-Woolfolk, 1999). The syntax subtest of the Comprehensive Assessment of Spoken Language core is reported here because this article focuses on grammatical development. Standard scores are reported in Table 1.

Table 1. Information about subjects.

Variable	*n*	*M*	*SD*
Age	51	37.90	2.92
Hearing measures			
BE-PTA (dB HL)	51	49.89	11.80
BE unaided SII (%)	51	24.18	18.43
4-kHz SL (dB SPL)	51	18.96	10.19
Speech/language measures			
GFTA-II raw	51	36.67	15.83
GFTA-II SS	51	89.64	16.70
CASL-syntax	49	86.73	14.09
MLU in words	51	2.38	0.72

Note. BE-PTA = better ear pure-tone average; HL = hearing loss; BE = better ear; SII = Speech Intelligibility Index; SL = sensation level; SPL = sound pressure level; GFTA-II = Goldman-Fristoe Test of Articulation–Second Edition; SS = standard score; CASL = Comprehensive Assessment of Spoken Language; MLU = mean length of utterance.

Data Collection

Hearing measures. Audiological testing was completed on all children. The results are shown in Table 1. Conditioned play audiometry was used to obtain air conduction pure-tone thresholds at 500, 1000, 2000, and 4000 Hz. These four values were averaged, and the lower value was retained for the better ear pure-tone average (BE-PTA). BE-PTA ranged from 31.25–82.5 dB HL (M = 49.89 dB HL).[1]

A second value, the Speech Intelligibility Index (SII) score (American National Standards Institute, 1997; Bentler, Cole, & Wu, 2011; French & Steinberg, 1947; Kryter, 1962) was also calculated for each ear, and the higher score was retained for use in analyses. Broadly speaking, SII measures how much access the child has to the speech spectrum given the degree and configuration of their HL, either with or without hearing aids (for further information on how SII was calculated, see Holte et al., 2012, and Koehlinger et al., 2013). Unaided SII for 65 dB input ranged from 0 to 74 in our data set, with possible values being from 0% (no access to speech) to 100% (complete access).

A third measure, aided sensation level (SL) at 4 kHz, was derived by computing the difference between the behavioral threshold at 4 kHz in sound pressure level in dB SPL and the output of the hearing aid in dB SPL for the 1/3 octave band centered at 4 kHz. This is a measure of how audible the average speech spectrum is at 4 kHz with hearing aids, which may give a more specific estimate of high-frequency speech audibility than SII or BE-PTA (McCreery & Stelmachowicz, 2011). Scores for this measure ranged from −5 to 36 dB SPL.

Articulation measures. All children retained for analysis had data from the Goldman-Fristoe Test of Articulation–Second Edition (GFTA-II; Goldman & Fristoe, 2000). Raw and standard scores from both the GFTA-II are reported in Table 1. The GFTA-II served as a global measure of articulation ability with the raw score (number of errors) used in the regression analyses below. It is worth remarking on the composition of the GFTA-II here given later measures that look exclusively at word final s/z use. The GFTA-II samples 39 consonants and clusters in English in various word positions for a total of 80 possible points. Although s/z appear in several words, they are each only scored once in word final position (2 of 77 points). Thus, using the GFTA-II as a continuous articulation measure was appropriate but did not address the question of whether production of word final s/z, in particular, influenced morpheme accuracy.

Information about the use of word final s/z was gathered via an experimenter-created single word naming task for 44 subjects. As a part of this task, children were tested on articulation via six monomorphemic words with word final consonants [s] and [z] (e.g., *bus, nose, cheese, horse, hose, buzz*). Children were given picture cards and asked to name/identify the object on the card. Responses were scored

[1]BE-PTA exceeded the study criterion upper limit (75 dB HL) for a few children who initially fit that hearing profile but had a hearing loss that later progressed beyond 75 dB HL. These children were retained in the study unless they received a cochlear implant. In the data for this article, five children had BE-PTA values above 75 dB HL.

as correct if children gave an approximation of the target phoneme (distortions were accepted as correct).

Eleven children did not participate in this task for various reasons, including fatigue and examiner error. In these cases, the subjects' language samples, described below, were analyzed for words that provided obligatory contexts for [s] and [z] as monomorphemic final consonants (e.g., *these, this, squeeze*). We computed percent correct use of monomorphemic word final [s] and [z] for four to seven opportunities. As mentioned previously, four of these 11 children who otherwise met criteria for participation did not have enough obligatory contexts (fewer than four) to separate articulation abilities from morphology skills and were excluded. Although we initially intended to use this as a continuous measure, the data were not normally distributed and therefore were treated categorically. Based on the criteria in the SLI literature, which typically uses an 80% cutoff (e.g., Leonard, Eyer, Bedore, & Grela, 1997; Rice, Wexler, & Hershberger, 1998), children were grouped into categories of poor (<80%) and good (>80%) use of word final [s] and [z] in later analyses. Table 2 shows the number of children in each group and the hearing information associated with these groups of children. Neither of these measures of word final –s and –z production assessed use in clusters directly.

Language sample elicitation. All children participated in 15-min conversational language samples (following Hadley, 1998) in which children played with play-doh and talked with a parent and an examiner. Of the 51 children who participated in the full 3-year-old battery of testing, 26 children who were HH also had language samples from a 5-min art gallery task following the protocol described in Adamson, Bakeman, and Deckner (2004). Because the number of obligatory contexts, $t(49) = 1.55$ and $p = .12$, and average accuracy, $t(49) = 1.16$ and $p = .25$, did not differ between cases where children had conversational samples only and conversational samples plus art gallery samples, these samples were added together when available in order to maximize the size of the language sample to be analyzed from each subject. Data collection methods and transcription conventions are reported in more detail in Holte et al. (2012) and Koehlinger et al. (2013). In general, samples were transcribed following Systematic Analysis of Language Transcripts (SALT) conventions (Miller & Iglesias, 2010), with some adjustments to enhance the ability to search for relevant grammatical morphology (e.g., copula and auxiliary were coded with unique codes, which is not standard SALT protocol). Intertranscriber reliability was computed for 10% of the language samples for each of the following criteria: utterance boundaries (*M* = 92%, range = 89%–95%), words produced (*M* = 95%, range = 92%–96%), and coding for bound morphology (*M* = 88%, range = 85%–90%).

Table 2. Hearing data grouped by children with high (>80%) and low (<80%) articulation skills for word final s/z.

Hearing measures	>80% (*n* = 36) *M*	>80% (*n* = 36) *SD*	<80% (*n* = 15) *M*	<80% (*n* = 15) *SD*	*p*
4-kHz SL (dB SPL)	20.08	8.79	16.27	12.93	.22
BE-unaided SII (%)	27.46	18.59	16.33	16.01	.048
BE-PTA (dB HL)	48.38	11.40	53.52	12.33	.16

Note. SL = sensation level; SPL = sound pressure level; BE = better ear; SII = Speech Intelligibility Index; BE-PTA = better ear pure tone average; HL = hearing loss.

The language samples allowed us to compute MLU in words for all subjects. MLU in words, as opposed to MLU in morphemes, was used so as to avoid penalizing the children who presented with grammatical morpheme-production difficulties. Information about MLU in words is reported in Table 1. The average language sample contained 128.31 utterances (*SD* = 57.77, range = 40–360). Recall that children with fewer than four obligatory contexts or 40 utterances in the sample were excluded; some children who are HH may present with greater language learning challenges than might be assumed from the information here. Sixteen children had between four and nine obligatory contexts; 27 had between 10 and 30 obligatory contexts; and eight had more than 30 contexts. Table 3 shows the average number of obligatory contexts per child per morpheme type broken out by sentence position and allomorph type. The distribution of contexts is uneven across the various cells, generally reflecting natural distribution of these contexts in English. For example, plurals are more common utterance finally and copulas are more common medially. As we will return to later, our choice of statistical method was designed to deal with the fact that different children contributed different numbers of responses.

Morphology coding. All utterances that provided an obligatory context for morphemes realized as /s/, /z/, or /ɪz/ were extracted from the language samples using SALT searches and coded. Each morpheme (*N* = 1,176) was coded for accuracy, morpheme type, sentence position, and allomorph. Accuracy was coded as correct or omitted. Although we planned to allow considerable variance to account for immature articulation skills, the majority of the productions coded as correct were reported by the transcribers to be adultlike approximations of the target (e.g., watch-ɪz, girl-z), and good reliability on transcription was achieved. Commission errors (e.g., *They is happy*) were discarded (*n* = 27). Table 4 illustrates the coding scheme used with sample utterances marked for morpheme type, accuracy, allomorph type, and sentence position. Morpheme type was coded as possessive, third-person singular, plural, copula, or auxiliary. If the morpheme type was not determinable from the utterance (e.g., *My cook my ones*), the item was discarded (*n* = 14).

Allomorph was coded as /s/, /z/, /ɪz/, and indeterminate. The allomorph was determined by the final phoneme of the target word stem in the transcription and not through acoustic analysis. For example, if a marker was preceded by a voiceless sound (e.g., *book*), then the allomorph was coded as /s/; word final voiced sounds were coded as /z/, and word final alvelo-patalal fricatives or affricates were coded as /ɪz/. If the allomorph was not determinable from the utterance as it was transcribed (e.g., J's gonna cut your

Table 3. Information about the distribution of obligatory contexts for each morpheme across sentence position and allomorph contexts.

	Medial				Final				All positions
Morpheme	**–s**	**–z**	**–iz**	**All**	**–s**	**–z**	**–iz**	**All**	**All allomorphs**
Plural									
M (*SD*)	1.56 (0.73)	2 (1.62)		2.31 (1.74)	2.25 (2.17)	4 (3.15)	1 (0)	4.85 (4.19)	5.9 (5.15)
Range	0–3	0–8		0–8	0–9	0–14	0–1	0–22	0–29
n	9	23		26	20	44	2	46	48
Possessive									
M (*SD*)	1 (0)	1.92 (1.56)		1.79 (1.48)		4.25 (5.85)		4.25 (5.85)	2.62 (4.38)
Range	0–1	0–5		0–5		0–13		0–13	0–18
n	2	12		14		4		4	16
Copula									
M (*SD*)	8.02 (6.91)	2.74 (1.83)	3.94 (4.88)	12.56 (10.69)			1.29 (0.76)	1.29 (0.76)	13.26 (11.58)
Range	0–33	0–7	0–25	0–45			0–3	0–3	0–51
n	49	34	36	50			7	7	50
Auxiliary									
M (*SD*)	2.08 (1.61)	2.59 (2.45)	1.17 (0.41)	2.79 (2.82)					2.79 (2.82)
Range	0–5	0–11	0–2	0–12					0–12
n	13	17	6	28					28
Third singular									
M (*SD*)	1.47 (0.99)	1.56 (0.86)	1 (0)	2.08 (1.63)	1 (n/a)	1 (0)		1 (0)	2.11 (1.65)
Range	0–4	0–4	0–1	0–7	0–1	0–1		0–1	0–7
n	15	18	2	25	1	5		5	27
All morphemes									
M (*SD*)	9.35 (7.80)	5.44 (4.83)	4.19 (5.05)	16.53 (13.24)	2.3 (2.18)	4.38 (3.51)	1.22 (0.67)	5.52 (4.95)	22.02 (17.25)
Range	0–34	0–21	0–26	1–56	0–9	0–14	0–3	0–23	4–74
n	49	43	36	51	20	45	9	46	51

Note. The mean (*M*) and standard deviation (*SD*) of opportunities was calculated using only those (*n*) children who had at least one obligatory context available. The range includes all children. The distribution of values reflects the natural distribution of contexts in English (e.g., auxiliary is rarely heard utterance finally, even in adult speech).

thing), the item was discarded (*n* = 12). These discards primarily resulted from the fact that names were replaced with initials at the time of transcription in order to protect subject privacy. Contracted copula and auxiliary forms of "is" were coded for allomorphs as described above. If the omission was an obligatory context that allowed contraction, it was treated as such. If a full form of "is" was required due to the phonetic context (e.g., *the princess happy*), it was coded as the syllabic allomorph.

Sentence position was coded as initial, medial, and final. All sentence initial morphemes were overtly produced, uncontracted forms of "is" (e.g., *is he happy?*) and were discarded (*n* = 26). Only one instance of elision contributed to the utterance final uses of "is." Thus, medial and final forms of all morphemes were analyzed, and 1,049 items (89.2% of the data) were retained for analysis. Because of the nature of English, sentence position and morpheme type are not independent; note, for instance, that there are no cases of auxiliary in utterance final position in our data. Statistical methods that account for uneven numbers of items per variable were selected with this in mind.

Statistical Method

Our goal was to determine what child factors (hearing, articulation skills) and utterance level factors (morpheme

Table 4. Sample utterances coded for morpheme type, accuracy, sentence position, and allomorph type.

Morpheme	Sample utterance	Accuracy	Sentence position	Allomorph type
Plural –s	Two snake.	Omitted	Final	/s/
	Make some eggs.	Correct	Final	/z/
Possessive	Elmo's daddy.	Correct	Medial	/z/
	Bert nose.	Omitted	Medial	/s/
Third singular	He jumps.	Correct	Final	/s/
	It go fast.	Omitted	Medial	/z/
Copula is	This my bowl.	Omitted	Medial	/ɪz/
	Ernie's all gone.	Correct	Medial	/z/
	That's mine.	Correct	Medial	/s/
Auxiliary is	He coloring.	Omitted	Medial	/z/
	He is jumping.	Correct	Medial	/ɪz/
	This going to be the big one.	Omitted	Medial	/ɪz/

of interest, allomorph, sentence position) are best predictors of accurate production of grammatical morphemes. A generalized linear mixed model with a logit link was used to relate the child factors to ability to produce grammatical morphemes. This approach weights the reliability of a factor based on how many data points are available, something that is critical given the unevenness of the data across children and morpheme types. A factor with more data has smaller confidence intervals and is more likely to be significant; a factor with fewer data has larger confidence intervals and is less likely to be significant. Thus, type II errors are most likely given the distribution of our data. A random subject effect was used to account for the repeated measurements per child because the number of obligatory contexts was not consistent across children. A total of 1,049 opportunities from 51 children were analyzed. Specifically, we wanted to determine the degree to which sentence position, morpheme, and allomorph affect the probability of correct production. In addition, hearing abilities and articulation, as measured by word final use of s/z and raw GFTA-II scores, were expected to influence correct usage. Interactions were also investigated and kept in the model if significant. In the statistical analysis, word final use of s/z is treated as a dichotomous variable where a score greater than 0.8 was considered "good word final articulation" and a score of less than 0.8 was considered "poor word final articulation" because this measure was not normally distributed and could not be treated as a continuous variable in the model. This variable was dichotomized, rather than categorized another way, because that best reflected subjects' actual performance. GFTA-II, which met assumptions for normality, was entered as a continuous variable. Analyses were carried out in PROC GLIMMIX of SAS v9.3.

Results

As predicted, both utterance level properties and child characteristics influenced accuracy, and these variables also interacted with each other, suggesting that both types of information are important for understanding language development in children who are HH. Results from the final model are given in Table 5. Using boxplots to help visualize the distribution of correct use, Figure 1 displays accuracy information by morpheme type, and Figure 2 displays the same information for allomorph and utterance position. In both plots, children with only one instance (thus placing their accuracy either at 0% or 100%) were excluded to avoid skewing the visual presentation of the data, though these data were included in the regression model. At the level of the individual utterance, allomorph affected overall accuracy (p = .018), but sentence position was nonsignificant as a main effect (p = .192).

Turning to children's abilities, we saw that children's articulation skills influenced accuracy through global articulation skills (GFTA-II raw scores, p = .0004). Even though the main effects for sentence position and word final s/z skills were not significant (p = .183), they did significantly interact with other variables and thus were retained in the model. Of all three hearing measures, only the 4-kHz SL measure was influential ($p < .0001$). Neither BE-PTA nor unaided SII were significant when entered alone or in concert with other variables and thus were excluded from the model.

Children's hearing and articulation abilities led to different outcomes depending on the allomorph being produced, with allomorph type interacting with 4-kHz SL (p = .002), word final s/z skills (p = .03), and GFTA-II raw scores (p = .03). Sentence position also interacted with word final s/z skills (p = .002). These interactions modulate the main effects reported above, and thus we discuss each in turn, beginning with allomorph type.

Although we had no specific predictions about morpheme type, it was included in the model to account for known variance associated with developmental trends. Morpheme type was significant (p = .014). Morpheme accuracy closely mirrored the profile reported for typically developing children. Plural and possessive were most accurate and auxiliary *is* and third-person singular *–s* were the least accurate; see Table 6 for odds ratios (OR) and p values. Morpheme type was the only utterance level variable that did not interact with either another utterance level variable or with a child characteristic. Morpheme type was not evenly distributed across allomorph or sentence position because of the natural distribution of these morphemes in English, which may have made it more difficult to detect these interactions. Elicited production methods would complement this approach to further explore this question.

Allomorph Type

Although there was a main effect of allomorph type, with /ɪz/ being more accurate on average than /s/ or /z/ forms (/z/ vs. /ɪz/ OR = 0.33, p = .004; /s/ vs. /ɪz/ OR = 0.30, $p < .001$; /s/ vs. /z/ OR = .90, p = .70; see Figure 2), allomorph type also interacted with all the child-level variables ($p < .05$). Children's overall articulation skills and word final s/z skills both predicted their overall accuracy with the allomorphs. As can be seen in Figure 3, regardless of GFTA-II raw score, children were highly accurate with /ɪz/. Global articulation skills affected /s/ and /z/ accuracy, with declines in morpheme use as the number of errors on the GFTA-II increased. Word final s/z skills also appeared to predict children's accuracy with the different allomorphs. Children with "good" word final s/z skills did not differ in their ability to produce the various allomorphs ($p > .10$). Children with "poor" articulation skills were more likely to produce /ɪz/ than /s/ (OR = 8.3, $p < .001$) or /z/ (OR = 5.3, p = .02).

Children's access to high-frequency sounds (4-kHz SL) also interacted with allomorph (p = .002). Apparently contradicting our hypothesis, children with low 4-kHz SL scores were poor at producing all three morphemes, with /ɪz/ being particularly poor. However, as shown in Figure 4, as 4-kHz SL increased, the odds of producing /ɪz/ accurately increased more rapidly than the odds of producing /s/ or /z/. This may primarily be a measurement problem: 4-kHz SL, although reflective of high-frequency hearing, may be too low in frequency to pick up on variation in /s/ and /z/ use,

Table 5. Effects included in the final regression model.

Effect	Degrees of freedom	Chi-square value	*p*
Allomorph	2	8.04	.018
Sentence position	1	1.70	.192
Morpheme	4	12.51	.014
Word final s/z skills	1	1.77	.183
4-kHz SL hearing	1	16.10	<.0001
GFTA-II raw score	1	12.70	.0004
Allomorph × 4-kHz SL	2	12.23	.002
Allomorph × Word Final s/z	2	6.86	.03
Allomorph × GFTA-II	2	7.02	.03
Sentence Position × Word Final s/z	1	9.81	.002

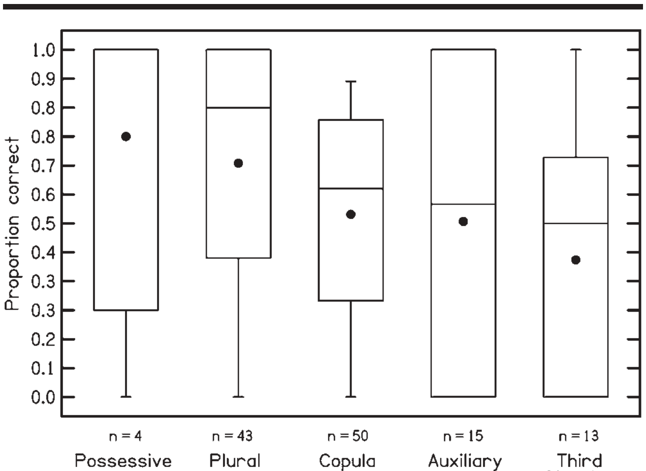
Note. Denominator degrees freedom = 1032. GFTA-II = Goldman-Fristoe Test of Articulation–Second Edition; SL = sensation level.

resulting in a flat (nonpredictive) line for these allomorphs. Use of other measures (e.g., 6-kHz SL) may result in better predictions for these sounds.

Sentence Position

Sentence position and word final s/z skills also interacted (p = .002). Children with "good" word final s/z skills are better at morphemes in sentence final position than in sentence medial position (OR = 3.7, p = .0004). Children with poor word final s/z production skills were equally poor at producing morphemes in both positions (p = .66). Two-way interactions between utterance position and allomorph type and three-way interactions involving child characteristics and utterance characteristics were not detected. This could be because they did not occur or it could be due to limited power. Larger samples with more evenly distributed exemplars may be required to rule out this possibility because these interactions have been observed in populations with NH using elicited production (e.g., Mealings et al., 2013).

Figure 1. Boxplot of accuracy of each morpheme type. Children who produced each morpheme only once were dropped from the figure to avoid skewing the visual representation of the data. The number of subjects included for each morpheme is noted above the labels.



Hearing and Articulation Skills

To further explore the relationship between hearing and children's accuracy, we also considered which hearing

Figure 2. Boxplot of accuracy of each allomorph in sentence medial and sentence final position. Children who produced each allomorph in a particular sentence position only once were dropped from the figure to avoid skewing the visual representation of the data. The number of subjects included for each morpheme is noted in the legend.

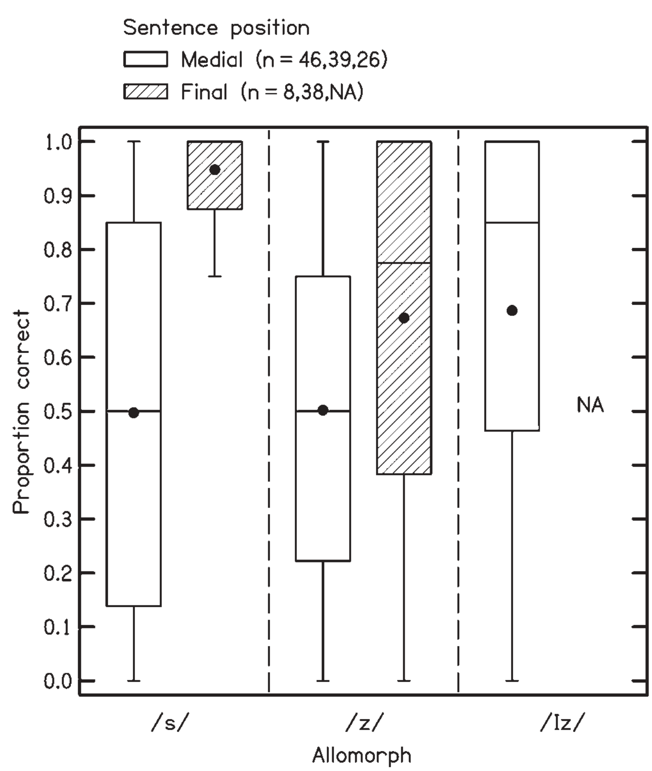


Table 6. Odds ratios (above the diagonal) and *p* values (below the diagonal) for Morpheme × Morpheme comparisons of accuracy.

Morpheme	Plural	Possessive	Copula	Auxiliary	Third singular
Plural	—	1.03	1.68	2.76	4.11
Possessive	.96	—	1.64	2.69	4.00
Copula	.13	.34	—	1.64	2.44
Auxiliary	.02	.08	.11	—	1.49
Third singular	.001	.02	.01	.35	—

measures predicted children's articulation skills. GFTA-II raw scores (the global articulation measure) were predicted well by BE-PTA (R^2 = .12) and unaided SII (R^2 = .11). The 4-kHz SL was not a significant predictor (R^2 = .04). Figure 3 shows the relationship between GFTA-II raw scores and allomorph accuracy; Figure 5 shows the relationship between GFTA-II raw scores, word final s/z production, and morpheme accuracy. It was not possible to run statistical analyses for children's word final s/z abilities because the distribution of the data violated assumptions about normality, but Figure 5 plots this information after converting both the GFTA-II and the articulation probes to percentages to assist the reader in interpreting these measures together.

Discussion

We evaluated the performance of 3-year-old children who are HH on their production of a variety of morphemes realized as /s/, /z/, and /ɪz/. In many ways, children who are HH are similar to their peers with NH; although the overall

Figure 3. Association between Goldman-Fristoe Test of Articulation–Second Edition raw scores (number of errors) and accuracy level for each allomorph.

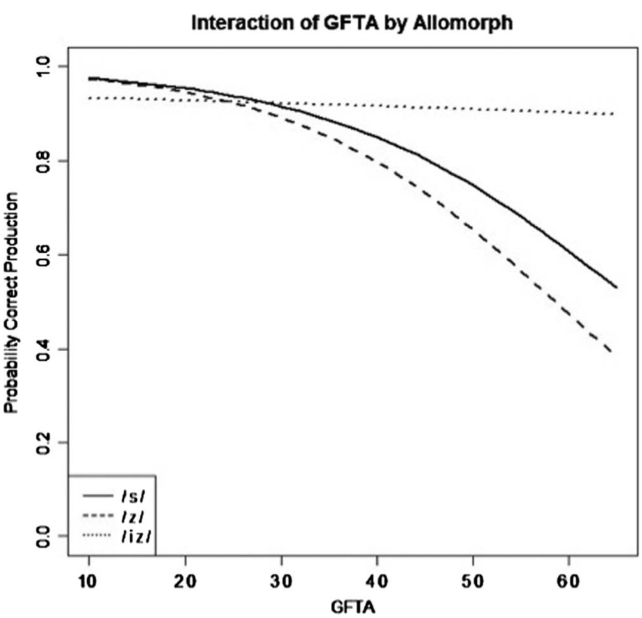


Figure 4. Association between 4-kHz sensation-level hearing measure and accuracy level for each allomorph.

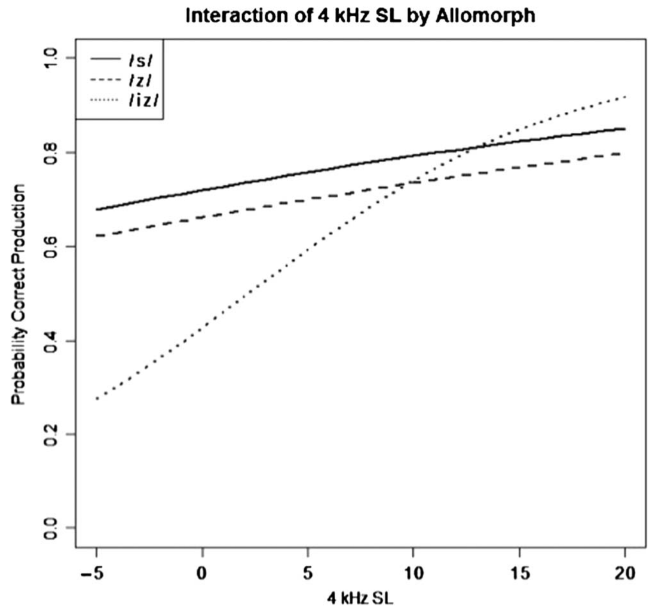
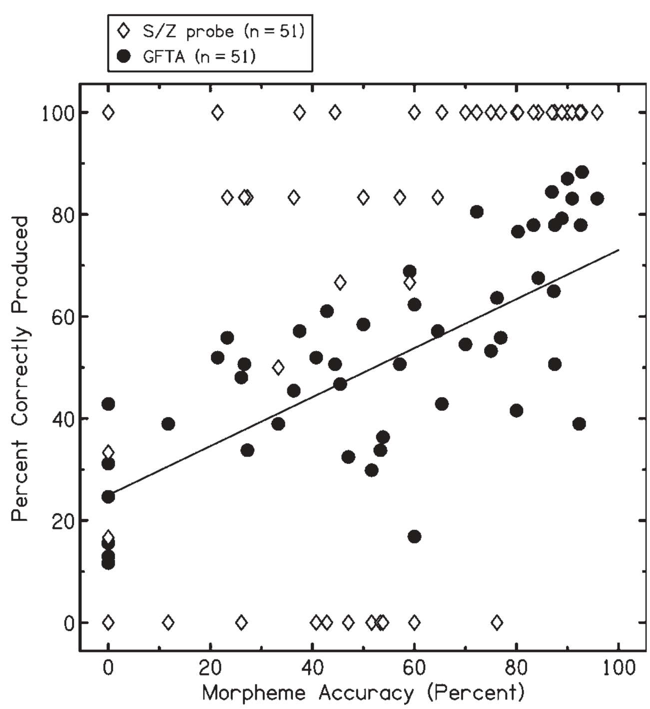


Figure 5. Relationship between percentage correct use of phonemes scored on the Goldman-Fristoe Test of Articulation–Second Edition (filled circles), word final s/z use on the articulation probe (open diamonds), and overall accuracy for morphemes. The trend line reflects Goldman-Fristoe Test of Articulation–Second Edition, data only.



accuracy rate is lower (Koehlinger et al., 2013), the relative accuracy levels for the five morphemes reported here generally mirror those reported elsewhere for children with NH (Brown, 1973).

The results for allomorph and sentence position hinged on children's articulation skills. Although overall accuracy was generally low, children who are HH with good word final articulation (s/z use >80%) tended to show patterns that approximate those seen in children with NH. For these children, all three allomorphs were produced equally well. For children with poor word final articulation (s/z use <80%), the allomorph /ɪz/ was produced correctly five to eight times more often than the /s/ and /z/ allomorphs. This is a reversal of the pattern seen in children with NH; that is, children with NH produce the /s/ and /z/ allomorphs more accurately than /ɪz/ (Berko, 1958). The results for sentence position also were affected by children's ability to use s/z word finally. Like children with NH, children who were HH with good word final s/z skills produced morphemes more accurately sentence finally than sentence medially (for children with NH, see Song et al., 2009). Children with poor word final s/z skills were equally poor at producing the morphemes in both positions, suggesting than any utterance final advantage was not being realized.

Articulation and Hearing

We hypothesized that the degree of HL and articulation skills would affect morphological accuracy. Thus, it was unexpected that neither BE-PTA nor unaided SII directly entered into the model. Both have been shown in the past to affect MLU and verb morphology use in children who are HH, suggesting an influence on grammatical development (Koehlinger et al., 2013). These verb morpheme composites used in previous studies also include syllabic forms like *am,* and *are* and other morphemes like past tense –ed that are not realized using fricatives. In contrast, in this study, 4-kHz SL was a significant predictor of s-related morphology, which includes both noun and verb markers. The 4-kHz SL measures audibility in a high-frequency region of the spectrum, an area known to be influential for perception and production of fricatives in morphological contexts (Stelmachowicz et al., 2001), a point we will return to when we consider the role of allomorphs on accuracy.

Global articulation skills are also strong predictors of grammatical morphology use, and it may be that the degree of HL indirectly influences grammatical development. BE-PTA and unaided SII predicted GFTA-II raw scores, but not morphological accuracy. The converse was true for 4-kHz SL scores: These scores predicted morphological accuracy, but not GFTA-II raw scores, our global measure of articulation. That said, BE-PTA only accounted for approximately 12% of the variance in the global measure of articulation. On average, every additional 10 dB of hearing led to a decrease of 4.4 raw score points (errors) on the GFTA-II. It seems surprising that BE-PTA accounted for so little of the variance in global articulation skills given the strong association between degree of HL and articulation reported in previous studies (Stelmachowicz, Pittman, Hoover, Lewis, & Moeller, 2004; Tomblin, Oleson, Ambrose, Walker, & Moeller, 2014). However, it is worth bearing in mind the age of the children included in this study. Recall that even 3-year-old children with NH are highly variable in their articulation abilities (Smit et al., 1990). The unexplained variance in overall articulation abilities may be due to maturational factors present in young children more generally and not unique to the population of children who are HH. BE-PTA may be a stronger predictor of both morphological accuracy and articulation skill for older children whose motor skills are more stable.

Because GFTA-II raw scores are not heavily weighted toward the use of /s/ and /z/, but instead sample a variety of phonemes in English across initial, medial, and final word positions, this measure is not as tightly related to s/z grammatical morpheme use as the word final s/z measure was. It would have been more transparent to relate hearing measures directly to the articulation of word final s/z, but these measures were highly skewed, and a parametric relationship could not be fit. Taken together, these results suggest that the general hearing profile has an indirect influence on s/z morpheme acquisition only by way of articulation ability. Aided access to high-frequency sounds, on the other hand, appears to be directly important for grammatical development of s/z morphemes. Further research, including measures of children's access to higher frequency sounds than measured here (measuring aided audibility at 6 or 8 kHz or using a high-frequency average for aided audibility), would enhance our understanding of the role of hearing in morphological development.

Input Frequency and Morpheme Availability

Morpheme type. It has been suggested that how often children with NH hear a grammatical marker influences how early it is acquired (Berko, 1958; Hsieh et al., 1999). Our findings for children who are HH that plurals, possessives, and copulas were most accurate and third-person singular was least accurate mirrors the order of acquisition documented for children with NH (Brown, 1973). Thus, we observe similar, but delayed, patterns of acquisition regardless of the level of grammatical development that we examine (Koehlinger et al., 2013). Certainly, longitudinal studies would be more reliable for determining order of acquisition, but accuracy rate tends to align well with age of mastery (Brown, 1973; de Villiers & de Villiers, 1973). As can be seen in Figure 1, when there are enough tokens produced by the individual child to judge, most children are not at either the ceiling or floor. Rather, many children are in the middle range once children who only have one opportunity to produce each form are excluded. The one exception is possessive, for which too few children had sufficient contexts to judge. The current results are somewhat surprising because McGuckian and Henry (2007) reported that children who are HH showed an alternate ranking of morpheme accuracy due to inconsistent input that was attributable to differences in perceptibility. The order of morphemes that we report does generally align with their work, with the exception of possessives. Our studies also differ considerably—they focused on a wider range of morphemes and older children than we do here. Relatively speaking, we have very few instances of possessives to analyze (see Table 3), and our results might change if we introduced more opportunities for production. Elicited production would enhance these findings by ensuring sufficient productions to analyze with confidence. Further study will be required to determine whether the order of acquisition differences that they reported for –ing and –ed generalize to a larger group of children.

Sentence position. Like the results from morpheme type, the results on sentence position generally matched previous findings (Song et al., 2009), though children's articulation abilities were particularly influential. Recall that Song et al. (2009) argued that utterance final placement both reduces motor planning demands by reducing the coarticulation requirements and enhances perceptibility. They convincingly showed that consonant clusters also lead to reduced accuracy. In this study, children with good word final s/z skills were 3.7 times more accurate in sentence final position than in sentence medial position. Children with poor word final s/z skills were equally poor at both sentence positions. Even when placed in facilitative situations, children with poor articulation skills were not able to demonstrate knowledge of grammatical morphemes realized as –s or –z. Our articulation screening measure did not evenly sample singletons and clusters, so we cannot ensure that difficulty producing word final –s clusters was not a problem, but the interaction between poor articulation skills and utterance position is notable nonetheless.

Allomorphs. In regard to a critical matter for questions about the role of input, we hypothesized that children who are HH would have higher levels of accuracy for inflectional markers realized as /ɪz/ as opposed to /s/ and /z/ because they would have more consistent access to the presence of the morpheme in the input when it is produced as a full syllable. Looking across all children, our hypothesis seems to be supported because the /ɪz/ allomorph is clearly more accurate than the /s/ or /z/ forms ($p < .0001$).

When we examine the results according to groups of children, two factors seem to be particularly influential with regard to allomorph use: word final s/z skills and access to high-frequency sounds. These two factors may be confounded. Approximately two thirds of the children produced word final s/z more than 80% of time, in line with criteria applied in standard studies of SLI. The remaining 15 children produced word final s/z between 0% and 80% of the time. As can be seen in Table 2, the two groups do not differ with regard to their overall hearing profile.

The performance of the good articulation group on each allomorph was similar to their overall performance: All three morphemes were between 64% and 68% correct. This would indicate that these children are applying rules for inflection evenhandedly across the different production contexts. It is still notable that, for this group, the /ɪz/ allomorph is trending toward being more accurate than /z/ (OR = 1.3) and that overall accuracy levels remain rather low.

For the poor articulation group, a wide range of abilities at producing word final s/z is present. Nonetheless, within this group, the use of /ɪz/ ($M = 0.88$) was clearly more accurate than the use of /s/ (OR = 8.6) or /z/ (OR = 5.3) allomorphs. At first this appears to be readily attributable to the difficulty that these children have with the final consonant sound by itself. As has been found in other studies, articulation skills are interfering with our ability to assess the language abilities of these children. Presumably remediation for articulation of word final s/z would lead to improvements in morphological accuracy.

However, the interaction between 4-kHz SL and allomorph suggests that perception may also be a contributing factor. The regression model predicted that children with poor access to high-frequency sounds would perform particularly poorly with /ɪz/ and at higher (but still nonmastery) levels for /s/ and /z/. As access to sounds in the 4-kHz range improved, use of /ɪz/ improved more rapidly than use of the other allomorphs. One explanation for these findings is related to measurement: We may need to extend the 4-kHz measure to 6 or 8 kHz in order to better capture the variability in the acquisition of s-related morphemes. Nonetheless, this is clearly a promising start because this measure provides insights that are entirely lacking from the more standard PTA and SII measures, which both contain limited weighting for frequencies above 2 kHz. Alternatively, although /s/ and /z/ are less audible to children with low 4-kHz SL scores, these two allomorphs may still be sufficiently common in their input that other factors aid in their acquisition. Because they are more common, they may be heard more often in an absolute sense, allowing children to identify and extract cues from other aspects of the speech stream (McMurray & Jongman, 2011). These cues, in combination with more robust input heard in quiet environments, may allow all children to acquire these forms. The /ɪz/ form, on the other hand, may be sufficiently rare such that only when a child has enough hearing in the right ranges can they detect the pattern and deploy the morpheme. This would be consistent with predictions of the surface hypothesis (Leonard, 1989), which argues that morpheme acquisition is influenced by the audibility of the morpheme in combination with its frequency and transparency.

Clinical Implications

Our findings put the emphasis on the need to jointly assess morpheme use and articulation skills in children with HL. Future studies should explore morpheme production through elicited production in order to better assess the role of morpheme type and consonant cluster use by these children. Assessment of the syllabic allomorph may provide a means of examining morpheme use in children who are HH with especially poor articulation skills. This allomorph may also lend itself to serving as an initial therapy target because it is easier to perceive and produce. Even if a child cannot produce the fricative, the clinician can detect use of the morpheme through the vowel. Targeting articulation directly may also be beneficial. Bow et al. (2004) and Moeller et al. (2010) showed that when articulation skills improved, so did morphological production and/or perception. Presentation of targets in utterance final position and manipulation of the phonological properties of the target word may also enhance accuracy during the early stages of therapy. Future work should examine whether these recommendations alter the efficacy of therapy for language-related targets. Investigations of whether improving audibility in the high frequencies leads to improved language skills are also warranted.

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References

Adamson, L. B., Bakeman, R., & Deckner, D. F. (2004). The development of symbol-infused joint engagement. *Child Development, 75*(4), 1171–1187. doi:10.1111/j.1467-8624.2004.00732.x

American National Standards Institute. (1997). *Methods for the calculation of the speech intelligibility index* (ANSI S3.5-1997). New York, NY: Author.

Bentler, R., Cole, W., & Wu, Y.-H. (2011). *Deriving an audibility index for frequency-lowered hearing aids*. Poster presentation at the American Auditory Society, Scottsdale, AZ.

Berko, J. (1958). The child's learning of English morphology. *Word, 14,* 150–177.

Bernthal, J. E., Bankson, N. W., & Flipson, P., Jr. (2013). *Articulation and phonological disorders: Speech sounds disorders in children* (7th ed.). New York, NY: Pearson.

Bow, C. P., Blamey, P. J., Paatsch, L. E., & Sarant, J. Z. (2004). The effects of phonological and morphological training on speech perception scores and grammatical judgments in deaf and hard-of-hearing children. *Journal of Deaf Studies and Deaf Education, 9,* 305–314. doi:10.1093/deafed/enh032

Brown, R. (1973). *A first language*. Cambridge, MA: Harvard University Press.

Carrow-Woolfolk, E. (1999). *Comprehensive Assessment of Spoken Language*. San Antonio, TX: The Psychological Association.

Chirlian, N. S., & Sharpley, C. F. (1982). Children's articulation development: Some regional differences. *Australian Journal of Human Communication Disorders, 10,* 23–30.

de Villiers, J. G., & De Villiers, P. (1973). A cross-sectional study of the acquisition of grammatical morphemes in child speech. *Journal of Psycholinguistic Research, 2,* 267–278.

Dodd, B., Holm, S., Hua, Z., & Crosbie, S. (2003). Phonological development: A normative study of British English-speaking children. *Clinical Linguistics and Phonetics, 17,* 617–643. doi:10.1080/0269920031000111348

Dodd, B., Woodhouse, L., & McIntosh, B. (1992). The linguistic abilities of young children with hearing impairment: First report of a longitudinal study. *Journal of Intellectual and Developmental Disability, 18,* 17–34. doi:10.1080/07263869200034781

Elfenbein, J. L., Hardin-Jones, M. A., & Davis, J. M. (1994). Oral communication skills of children who are hard of hearing. *Journal of Speech and Hearing Research, 37*(1), 216–226. doi:10.1044/jshr.3701.216

Fisher, H., & Logemann, J. (1971). *Fisher-Logemann Test of Articulation Competence*. Boston, MA: Houghton Millflin Co.

French, N., & Steinberg, J. (1947). Factors governing the intelligibility of speech sounds. *The Journal of the Acoustical Society of America, 19,* 90–119. doi:10.1121/1.1916407

Goffman, L., & Leonard, J. (2000). Growth of language skills in preschool children with specific language impairment: Implications for assessment and intervention. *American Journal of Speech-Language Pathology, 9,* 151–161. doi:10.1044/1058-0360.0902.151

Goldman, R., & Fristoe, M. (2000). *Goldman-Fristoe Test of Articulation–Second Edition*. Circle Pines, MN: American Guidance Service.

Gordon, T. G. (1987). Communication skills of mainstreamed hearing-impaired children. In H. Levitt, N. C. McGarr, & D. Geffner (Eds.), *Development of language and communication skills in hearing-impaired children* (ASHA Monographs No. 26, pp. 108–122). Rockville, MD: American Speech-Language-Hearing Association.

Hadley, P. A. (1998). Language sampling protocols for eliciting text-level discourse. *Language, Speech, and Hearing Services in Schools, 29,* 132–147. doi:10.1044/0161-1461.2903.132

Holte, L., Walker, E., Oleson, J., Spratford, M., Moeller, M. P., Roush, P., . . . Tomblin, J. B. (2012). Factors influencing follow-up to newborn hearing screening for infants who are hard of hearing. *American Journal of Audiology, 21*(2), 163–174. doi:10.1044/1059-0889 (2012/12-0016)

Hsieh, L., Leonard, L. B., & Swanson, L. (1999). Some differences between English plural noun inflections and third singular verb inflections in the input: The contributions of frequency, sentence position, and duration. *Journal of Child Language, 26,* 531–543.

Joint Committee on Infant Hearing. (2007). Position statement: Principles and Guidelines for Early Hearing Detection and Intervention Programs. *Pediatrics, 120,* 898–921. doi:10.1542/peds.2007-2333

Koehlinger, K. M., Owen Van Horne, A. J., & Moeller, M. (2013). Grammatical outcomes of 3- and 6-year-old children who are hard of hearing. *Journal of Speech, Language, and Hearing Research, 56,* 1701–1714. doi:10.1044/1092-4388 (2013/12-0188)

Kryter, K. D. (1962). Validation of the articulation index. *The Journal of the Acoustical Society of America, 34,* 1698–1702. doi:10.1121/1.1909096

Larsen-Freeman, D., & Long, M. H. (1991). *An introduction to second language acquisition research*. London, United Kingdom: Longman.

Leonard, L. B. (1989). Language learnability and specific language impairment in children. *Applied Psycholinguistics, 10*(2), 179–202. doi:10.1017/S0142716400008511

Leonard, L. B., Eyer, J., Bedore, L. M., & Grela, B. G. (1997). Three accounts of the grammatical morpheme difficulties of English-speaking children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 40,* 741–753. doi:10.1044/jslhr.4004.741

McCreery, R. W., & Stelmachowicz, P. G. (2011) Audibility-based predictions of speech recognition for children and adults with normal hearing. *The Journal of the Acoustical Society of America, 130,* 4070–4081. doi:10.1121/1.3658476

McGowan, R. S., Nittrouer, S., & Chenausky, K. (2008). Speech production in 12-month-old children with and without hearing loss. *Journal of Speech, Language, and Hearing Research, 51,* 879–888. doi:10.1044/1092-4388(2008/064)

McGuckian, M., & Henry, A. (2007). The grammatical morpheme deficit in moderate hearing impairment. *International Journal of Language & Communication Disorders, 42,* 17–36. doi:10.1080/13682820601171555

McMurray, B., & Jongman, A. (2011). What information is necessary for speech categorization? Harnessing variability in the speech signal by integrating cues computed relative to expectations. *Psychological Review, 118,* 219–246. doi:10.1037/a0022325

Mealings, K. T., Cox, F., & Demuth, K. (2013). Acoustic investigations into the later acquisition of syllabic –es plurals. *Journal of Speech, Language, and Hearing Research, 56,* 1260–1271. doi:10.1044/1092-4388(2012/12-0163)

Mealings, K. T., & Demuth, K. (2014). Cluster reduction and compensatory lengthening in the acquisition of possessive –s. *Journal of Child Language, 41,* 690–704. doi:10.1017/S0305000913000093

Miller, J. F., & Iglesias, A. (2010) Systematic Analysis of Language Transcripts (SALT), Version 9. Madison, WI: University of Wisconsin-Madison.

Moeller, M. P., Hoover, B., Putman, C., Arbataitis, K., Bohnenkamp, G., Peterson, B., . . . Stelmachowicz, P. G. (2007). Vocalizations of infants with hearing loss compared to infants with normal hearing: Part I—Phonetic development. *Ear and Hearing, 28*(5), 605–627. doi:10.1097/AUD.0b013e31812564ab

Moeller, M. P., McCleary, E., Putman, C., Tyler-Krings, A., Hoover, B., & Stelmachowicz, P. (2010). Longitudinal development of phonology and morphology in children with late-identified mild-moderate sensorineural hearing loss. *Ear and Hearing, 31*(5), 625–635. doi:10.1097/AUD.0b013e3181df5cc2

Norbury, C. F., Bishop, D. V. M., & Briscoe, J. (2001). Production of English finite verb morphology: A comparison of SLI and mild-moderate hearing impairment. *Journal of Speech, Language, and Hearing Research, 44,* 165–178. doi:10.1111/1469-7610.00726

Prather, E. M., & Hedrick, D. L. (1975). Articulation development in children aged two to four years. *Journal of Speech and Hearing Disorders, 40,* 179–191.

Rice, M. L., & Wexler, K. (2001). *Rice Wexler Test of Early Grammatical Impairment*. San Antonio, TX: The Psychological Corporation.

Rice, M. L., Wexler, K., & Hershberger, S. (1998). Tense over time: The longitudinal course of tense acquisition in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 41,* 1412–1431. doi:10.1044/jslhr.4106.1412

Smit, A. B., Hand, L., Freilinger, J. J., Bernthal, J. E., & Bird, A. (1990). The Iowa articulation norms project and its Nebraska replication. *Journal of Speech and Hearing Disorders, 55,* 779–798. doi:10.1044/jshd.5504.779

Song, J., Sundara, M., & Demuth, K. (2009). Phonological constraints on children's production of English third person singular -s. *Journal of Speech, Language, and Hearing Research, 52,* 623–642. doi:10.1044/1092-4388(2008/07-0258)

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., & Lewis, D. E. (2001). Effect of stimulus bandwidth on the perception of /s/ in normal- and hearing-impaired children and adults. *The Journal of the Acoustical Society of America, 110,* 2183–2190. doi:10.1121/1.1400757

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., & Lewis, D. E. (2002). Aided perception of /s/ and /z/ by hearing-impaired children. *Ear and Hearing, 23,* 316–324. doi:10.1097:01.AUD.0000027406.51909.06

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., Lewis, D. E., & Moeller, M. P. (2004). The importance of high-frequency audibility in the speech and language development of children with hearing loss. *Archives of Otolaryngology, Head, and Neck Surgery, 130,* 556–562. doi:10.1001/archotol.130.5.556

Sundara, M., Demuth, K., & Kuhl, P. K. (2011). Sentence-position effects on children's perception and production of English third person singular -s. *Journal of Speech, Language, and Hearing Research, 54,* 55–71. doi:10.1044/1092-4388(2010/10-0056)

Templin, M. (1957). *Certain language skills in children: Their development and interrelationships* (Institute of Child Welfare Monograph Series, No. 26). Minneapolis, MN: University of Minnesota.

Theakston, A. L., & Lieven, E. V. (2008). The influence of discourse context on children's provision of auxiliary BE. *Journal of Child Language, 35,* 129–158. doi:10.1017/S0305000907008306

Theodore, R. M., Demuth, K., & Shattuck-Hufnagel, S. (2011). Acoustic evidence for positional and complexity effects on children's production of plural –s. *Journal of Speech, Language, and Hearing Research, 54,* 539–548. doi:10.1044/1092-4388(2010/10-0035)

Tomblin, J. B., Oleson, J., Ambrose, S. E., Walker, E., & Moeller, M. P. (2014). The influence of hearing aids on the speech and language development of children with hearing loss. *JAMA Otolaryngology Head and Neck Surgery, 140*(5), 403–409. doi:10.1001/jamaoto.2014.267