Research Article

The Role of Frequency in Learning Morphophonological Alternations: Implications for Children With Specific Language Impairment

Ekaterina Tomas,^a Katherine Demuth,^{b,c} and Peter Petocz^d

Purpose: The aim of this article was to explore how the type of allomorph (e.g., past tense *buzz*[d] vs. *nod*[əd]) influences the ability to perceive and produce grammatical morphemes in children with typical development and with specific language impairment (SLI).

Method: The participants were monolingual Australian English-speaking children. The SLI group included 13 participants (mean age = 5;7 [years;months]); the control group included 19 children with typical development (mean age = 5;4). Both groups performed a grammaticality judgment and elicited production task with the same set of nonce verbs in third-person singular and past tense forms.

Results: Five-year-old children are still learning to generalize morphophonological patterns to novel verbs, and syllabic /əz/ and /əd/ allomorphs are significantly more challenging to produce, particularly for the SLI group. The greater phonetic content of these syllabic forms did not enhance perception.

Conclusions: Acquisition of morphophonological patterns involving low-frequency allomorphs is still underway in 5-year-old children with typical development, and it is even more protracted in SLI populations, despite these patterns being highly predictable. Children with SLI will therefore benefit from targeted intervention with low-frequency allomorphs.

It has long been known that grammatical morphemes tend to be acquired in a certain order, and that some morphemes take longer to master than others (Berko, 1958; Brown, 1973; de Villiers & de Villiers, 1973). For example, English plural *-s* is believed to be learned around 2.5 years, whereas regular past *-ed* is thought to be acquired later, around the age of 4 (Brown, 1973). Before they learn to consistently use grammatical morphemes, however, it is typical for English-speaking children to variably omit them in obligatory contexts, producing bare stems, e.g., *She laugh every day* (Clark, 2003). This article, therefore, explores the possible factors responsible for the order and age of morpheme acquisition in children.

The underlying reasons for the variable use of grammatical morphemes, as well as the order in which they are acquired, have been the focus of much scientific attention over the past several decades. Different theoretical approaches have been proposed to explore the patterns of morpheme acquisition in young children. The syntactic approach has focused primarily on why some grammatical morphemes start appearing before others in spontaneous speech. Some have suggested that the protracted acquisition of tense and agreement morphemes in English-speaking children is due to semantic complexity of verbal compared with nominal morphemes (de Villiers & de Villiers, 1973). An alternative hypothesis has been proposed, the optional infinitive (Wexler, 1994), where the syntactic complexity associated with verb movement contributes to the later mastery of verbal grammatical morphemes. This approach predicts that children under 3 years are still at the so-called “optional infinitive” stage of grammatical development, where they have not fully acquired the syntactic movement operations needed to trigger consistent use of tense/agreement morphemes. However, although these studies try to account for the later mastery of verbal compared with nominal morphemes, they do not address the question of why we often observe similar

^aNeurolinguistics Laboratory, National Research University Higher School of Economics, Moscow, Russia

^bARC Centre of Excellence in Cognition and its Disorders, Department of Linguistics, Macquarie University, North Ryde, Australia

^cSanta Fe Institute, New Mexico

^dDepartment of Statistics, Macquarie University, North Ryde, Australia

Correspondence to Ekaterina Tomas: ekaterina.tomas@gmail.com

Editor: Sean Redmond

Associate Editor: Filip Smolik

Received April 7, 2016

Revision received September 13, 2016

Accepted November 8, 2016

https://doi.org/10.1044/2016_JSLHR-L-16-0138

Disclosure: This study was partially funded by Widex. The authors report no other conflicts of interest.

patterns of omission across different types of morphemes (e.g., nominal and verbal inflection; Tomas, Demuth, Smith-Lock, & Petocz, 2015; Leonard, 2016), nor the variable production of a given morpheme in different phonological/prosodic contexts.

The prosodic licensing hypothesis proposes that young children's variable production of grammatical morphemes may depend on the phonological/prosodic context in which they occur (Demuth, 2014). For example, it has been shown that young children are more likely to produce third person singular *-s* when it appears in utterance final position, as in *Every day she laughs*, compared with when it appears utterance medially, as in *She laughs every day* (Song, Sundara, & Demuth, 2009). This has been explained in terms of final-phrase lengthening: The final syllable of an utterance tends to be longer in duration, which leaves more time to articulate all target coda consonants/morphemes. It has also been found that phonological complexity plays a role in children's production of inflectional morphology. In particular, inflectional morphemes that are part of a singleton coda consonant, as in *The bird flies*, start appearing before those that are part of a consonant cluster, as in *The boy sits*. This has been observed in a number of studies with 2-year-old typically developing (TD) children producing third person singular *-s* and plural forms of nouns (Mealings, Cox, & Demuth, 2013; Song et al., 2009, 2013; Theodore, Demuth, & Shattuck-Hufnagel, 2011, 2012, 2015). Taken together, these studies suggest that the variable use and later emergence of some morphemes could be due to children's limited phonological abilities, and that certain phonological/prosodic contexts may therefore enhance or inhibit children's early morpheme production.

However, it has also been proposed that perceptual salience may play a role in which morphemes are more likely to be produced. Leonard and his colleagues have pursued this idea in terms of the surface account, suggesting that the later acquisition of certain grammatical morphemes in the speech of children with specific language impairment (SLI) is due to their low perceptual salience (Leonard et al., 2003). More recent perceptual research has shown that this also accounts for much of the variable perceptual sensitivity to the same morphemes in different prosodic contexts and/or greater sensitivity to some allomorphs than others. For example, Sundara, Demuth, and Kuhl (2011) have shown that it is easier for infants to perceive third person singular *-s* utterance finally (where it is longer in duration) than utterance medially (where it is much shorter). This has recently been replicated in an article by Dube, Kung, Peter, Brock, and Demuth (2016) with adults in a sentence-processing task using electroencephalograms. In other studies using an intermodal preferential looking paradigm, Davies, Xu Rattanasone, and Demuth (2017a) have shown that 2-year-old children are more sensitive to plural */s/* compared with plural */z/* allomorphs (as in *cats* vs. *dogs*). Again, this appears to be due to issues of perceptual salience (plural word-final */s/* is longer than plural word-final */z/*), rather than due to frequency effects (plural */z/* is actually much more frequent than plural */s/*). Thus, at least in this

type of listening task, perceptual salience seems to override the effects of morpheme (or allomorph) frequency. However, it has also long been known that the frequency with which certain linguistic forms are used in the input can determine the rate at which they are acquired. This has been clearly demonstrated in the case of syllable and prosodic word structures, where the higher-frequency forms are acquired earlier (Levelt, Schiller, & Levelt, 2000; Roark & Demuth, 2000).

Usage-based approaches to young children's acquisition of grammar (Goldberg, 2006; Tomasello, 2003, 2009) suggest that by about 1 year of age, children start systematically applying their "pattern-finding" ability to learning morphosyntax of their first language. However, not all the patterns are equally easy for children to learn, and it is not yet fully understood how this may be differentially realized in speech perception/comprehension versus speech production. It thus appears that syntactic, phonological, perceptual, and frequency factors may all play a role in the process of morpheme acquisition. Syntactic complexity gives insight into the relative order of acquisition (e.g., later mastery of tense/agreement morphemes), whereas phonological/prosodic structure helps to explain the variable use of grammatical morphemes in different phonological/prosodic environments. Perceptual approaches predict that the more perceptually salient morphemes/allomorphs will be acquired earlier, as does the frequency approach. However, none of these frameworks fully explains why all formal representations (i.e., allomorphs) of a particular grammatical morpheme do not appear at the same time in children's spontaneous speech.

Morphophonological Effects on Morpheme Production

In English, the majority of phonological processes are associated with morphological alternations. For example, the past tense morpheme has three allomorphs: */t/*, */d/*, and */əd/*, as in *washed* /wɒʃt/,¹ *cleaned* /kliːnd/, and *dusted* /dʌstəd/. Likewise, third person singular *-s* can take the form of */s/*, */z/*, or */əz/*, as in *sits* /sɪts/, *runs* /rʌnz/, or *dances* /dænsəz/. These same three representations are also found in nominal plural (e.g., *cats* /kæts/, *dogs* /dɒgz/, *fishes* /fɪʃəz/) and in the possessive (e.g., *cat* /s/, *dog* /z/, or *fish* /əz/ *tail*). The choice of appropriate allomorph is highly predictable and relies on phonological environment: The voiceless */s/* and */t/* are added to stems ending in voiceless consonants, the voiced */z/* and */d/* follow words ending in a voiced segment, and the syllabic */əz/* and */əd/* occur after sibilants and alveolar stops, respectively.

It is important to note that syllabic allomorphs, which add an unstressed syllable to the stem (i.e., */əz/* and */əd/*), often appear later in spontaneous speech than segmental allomorphs, which add a single consonant to the stem (i.e.,

¹The International Phonetic Alphabet-based vowel phoneme symbols used throughout this article are adjusted for Australian English and used as recommended in Harrington, Cox, and Evans (1997).

/t/ or /d/, and /s/ or /z/; Brown, 1973). This tendency has also been observed in experimental settings, both during elicited production tasks (Berko, 1958) and elicited imitation tasks (Mealings et al., 2013). In addition, the delayed acquisition of syllabic allomorphs has also been observed in Spanish (Kernan & Blount, 1966): In plural forms of nouns, allomorph *-s* was often overgeneralized to syllabic *-es* environments, as in *papels* for *papeles* (papers) and *camions* for *camiones* (trucks).

Recent investigations into Dutch and German also have reported children's variable use of some allomorphs, explaining this in terms of children's emerging sensitivity to morphophonological alternations (Kager, van der Feest, Fikkert, Kerkhoff, & Zamuner, 2007; Kerkhoff, 2003, 2007; van de Vijver & Baer-Henney, 2011, 2012, 2013; Zamuner & Johnson, 2011; Zamuner, Kerkhoff, & Fikkert, 2011). These studies have not only demonstrated the protracted mastery of some types of allomorphs in young children, but they have also shown that children's ability to generalize (i.e., apply to new/nonce words) even regular morphophonological patterns such as final devoicing in Dutch (e.g., [bet]_{Nom.sg} and [bedə]_{Nom.pl}; bed) only fully develops by the age of 5 or 6 years (Kerkhoff, 2007; Zamuner et al., 2011).

It has never been entirely clear why the syllabic forms of inflection are so difficult to master for learners of English. The most likely explanation involves frequency effects. The syllabic allomorphs of all grammatical morphemes have much lower type and token frequency of occurrence (only 5%) compared with the segmental allomorphs in child-directed speech (Brown, 1973; Jolly & Plunkett, 2008; Mealings et al., 2013; Tomas et al., 2015). Consider, for example, the type/token frequencies for present and past tense segmental versus syllabic inflections as drawn from child-directed speech in the Providence Corpus (Demuth, Culbertson, & Alter, 2006) between the ages of 2;10 and 3;1 (years;months; Table 1). The lower frequency of the syllabic forms could lead to protracted acquisition, affecting both perception and production. As an alternative, the later acquisition of syllabic allomorphs could be due to articulatory/speech-planning difficulties, where a syllabic allomorph constitutes a short unstressed syllable, which is challenging to produce for young children (Leonard, Eyer, Bedore, & Grela, 1997; Leonard et al., 2003). In this case, we might predict that the

perception of syllabic morphemes could be enhanced, but not production.

Morpheme Acquisition in Children With SLI

Children are diagnosed as having SLI if their language development is delayed despite normal physical and cognitive abilities (Leonard, 1998; Bishop & Norbury, 2008). Several theories have been proposed to explain the underlying linguistic factors responsible for the protracted acquisition of speaking skills in children with SLI. The extended optional infinitive hypothesis has suggested that their deficits lie in the syntactic domain (Cleave & Rice, 1997; Rice, Tomblin, Hoffman, Richman, & Marquis, 2004; Rice & Wexler, 1996; Rice, Wexler, & Cleave, 1995), predicting that the optional infinitive stage of development for children with SLI is extended/protracted. Others have focused more on phonological deficits in these children (Goad, 1998; Marshall and van der Lely, 2007; Polite, 2011; Ramus, Marshall, Rosen, & van der Lely, 2013). For example, Marshall and van der Lely (2007) observed that children with SLI were worse at producing past tense morphemes with increased phonotactic complexity, as in *sewed* /soʊd/ versus *yelled* /jɛld/ versus *danced* /dænst/ (see also Marshall, Harcourt-Brown, Ramus, & van der Lely, 2009; Polite, 2011). They also noted that words such as *danced* occur in morphologically complex forms that are phonotactically less frequent, both in the input that children hear and in their own productions, which is likely to additionally constrain morpheme production.

As reported for TD children, various morphophonological alternations appear to be challenging to produce and generalize for the SLI population as well. For example, it has been shown that, for English-speaking children with SLI, the successful production of past tense *-ed* (Marchman, Wulfeck, & Weismer, 1999; Oetting & Horohov, 1997; Tomas et al., 2015), third person singular *-s*, and possessive *-s* (Tomas et al., 2015) depends on the allomorph. In particular, syllabic allomorphs are omitted significantly more often (Tomas et al., 2015). Recent studies of Dutch and French report that morphophonological alternations associated with allomorphy, liaison, contraction, and elision may also be challenging for these children (Kerkhoff, 2007; Rispens & De Bree, 2014; Royle & Stine, 2013). Similar effects have also been found in other atypical populations,

Table 1. Proportions of segmental (vs. syllabic) morphemes used in (Providence Corpus) child-directed speech.

Morpheme	Total tokens	One-proportion test results and confidence intervals		
		Segmental allomorphs (proportion)	p value	95% confidence interval
Past <i>-ed</i>	467	0.83	< .001*	[0.79, 0.86]
Present <i>-s</i>	698	0.95	< .001*	[0.93, 0.96]
Possessive <i>-s</i>	242	0.90	< .001*	[0.86, 0.94]

Note. Table is adopted from Tomas et al. (2015).

*Statistically significant values.

such as Dutch- and German-speaking individuals with aphasia (Grijzenhout & Penke, 2005), suggesting possible vulnerability of the general mechanisms underlying morpho-phonological processes across various populations.

To summarize, it appears that, in both TD children and children with SLI, the acquisition of grammatical morphology depends on several linguistic factors, including syntactic and phonological/prosodic, as well as morpho-phonological knowledge. However, although the contribution of both syntactic and phonological factors has been explored in great detail, it is unclear how and when children with SLI and their TD peers master the morphophonological processes of their native language. It is also not known how robust these morphophonological effects are, because previous studies had a limited number of syllabic morpheme tokens. It is therefore not clear when either group of children would be able to generalize the full range of allomorphs to nonce words, because the syllabic allomorphs /əz/ and /əd/ have very low frequency despite their high predictability/regularity. What is needed is a study (a) comparing children's perception and production abilities across different morphemes and allomorphs, (b) comparing children with SLI and their TD peers, and (c) involving a design that controls for lexical frequency, phonotactic probability, and the number of items per condition.

Present Study

The aim of the present study was therefore to explore the perception and production of segmental versus syllabic allomorphs by Australian English-speaking TD children and children with SLI. In order to establish how systematic the correlation between allomorphy and morpheme acquisition might be, we investigated these phenomena in two grammatical morphemes: third person singular *-s* and past tense *-ed*. We focused on establishing whether the two populations perceive and produce morphophonological alternations in a similar way, and if 5-year-old children in either group are able to generalize these patterns to nonce verbs.

On the basis of previous reports about the later emergence of syllabic allomorphs in children's speech, we predicted that both /əz/ and /əd/ would be produced with lower accuracy than segmental /z/ and /d/. We also expected that perceiving syllabic allomorphs might be less challenging than producing them, because syllabic allomorphs have more phonological content than their segmental counterparts (Mealings et al., 2013). Therefore, if the omission of syllabic allomorphs is primarily associated with articulatory/speech-planning challenges, we might expect to find similar performance across segmental and syllabic allomorphs during a perception/grammaticality judgment task. We additionally anticipated that the TD group would be able to consistently use both types of allomorphs with nonce verbs. However, we expected lower generalization abilities for the SLI population, especially when producing syllabic forms, because the language abilities of children with SLI are known to be greatly affected by frequency effects (Oetting & Horohov, 1997; Rispens & De Bree, 2014).

Method

Participants

The participants were monolingual Australian English-speaking children with SLI and TD controls. The SLI group included 13 participants (11 boys, 2 girls) aged between 5;0 and 6;3 ($M = 5;7$, $SD = 0;6$), and the controls were 19 TD children (11 boys, 8 girls) also aged between 5;0 and 6;3 ($M = 5;4$, $SD = 0;4$). The main reason for only including age-matched controls was that language-matched children (i.e., those around 3 years of age) would not yet be able to complete the tasks used in this study: a grammaticality judgment task and a "wug" test.

The participants in the TD group were recruited from the Sydney metropolitan area. Out of 21 recruited children, two potential participants did not meet the eligibility criteria and were subsequently excluded from the study: One had a history of hearing problems, and the other was raised by bilingual parents (native speakers of Cantonese).

The participants with SLI were recruited and tested in one of the special schools in Perth, Western Australia, the North East Metropolitan Language Development Centre. These centers provide specialized language and academic intervention for children with language-learning difficulties. Entry into the school requires being diagnosed as having SLI by a speech-language pathologist. Children of eligible age were each given the information and consent forms, which were distributed by the school authorities. Both children and their parents/guardians were required to give consent to take part in the study. The parents/children who returned signed forms ($n = 58$) were then invited to participate in the screening process. Of these, 44 potential participants proved ineligible due to their performance on the standardized tests (see next section). In particular, if the child demonstrated either below average nonverbal IQ on the Kaufman Brief Intelligence Test–Second Edition (KBIT-2; Kaufman & Kaufman, 2004) or had a marginal score on the Clinical Evaluation of Language Fundamentals Preschool-2 (CELF-P2; Wiig, Secord, & Semel, 2006) language assessment (i.e., 86–88 points), their testing was discontinued. The recruitment and testing procedures were approved by the Macquarie University Human Research Ethics Committee; the collaboration with North East Metropolitan Language Development Centre received additional approval from the Department of Education of Western Australia.

Standardized Assessments

To determine eligibility for the study, a battery of standardized tests was used prior to the experiment (see Table 2). The screenings were carried out during a separate session, in most cases, a few days prior to the experiment. The screenings assessed the participants' (a) language skills, using core language subtests such as the Sentence Structure, Word Structure, and Expressive Vocabulary in CELF-P2; (b) nonverbal IQ, using KBIT-2; (c) morphological development, with the screener pack of the Test of Early Grammatical

Table 2. Mean (SD) scores on language (Clinical Evaluation of Language Fundamentals Preschool-2 [CELF-P2] and Test of Early Grammatical Impairment [TEGI]) and cognition (Kaufman Brief Intelligence Test [KBIT-2]) tests for the typically developing (TD) children and children with specific language impairment (SLI) by group.

Group	Language skills: CELF-P2	Tense morphemes: TEGI probe score	Cognitive skills: KBIT-2
TD	110.2 (11.9)	95.9 (7.1)	109.5 (12.1)
SLI	78.5 (4.9)	54.0 (18.7)	93.8 (7.8)

Impairment (TEGI; Rice & Wexler, 2001); and (d) gross motor articulatory skills, using a 3-min nonword repetition task. Table 2 includes only the scores of eligible participants, because testing of children who failed at least one of the subtests was discontinued.

The standardized language and cognition assessments (CELF-P2, KBIT-2, and TEGI) were carried out either by the experimenter (i.e., a linguist trained by a professional speech-language pathologist), who screened the TD controls in Sydney, or by a speech-language pathologist who assisted with testing the participants with SLI on site in Western Australia. Each of the participants from the SLI group showed significantly lower performance on the language/CELF-P2 test than expected for their age (i.e., scoring less than 85 points, or > 1 SD below the mean) along with an average or higher IQ/KBIT-2 score (i.e., scoring above 85 points, or < 1 SD below the mean). In contrast, the TD children had an average or higher score (i.e., above 85 points) on both the KBIT-2 and CELF-P2 language tests.

Because children with SLI form a heterogeneous population and do not always have the same types of difficulties in acquiring grammatical morphemes (Conti-Ramsden & Botting, 1999), we carried out the TEGI screening test to ensure that participants in the SLI group had a similar clinical profile. All participants in the TD group successfully passed the TEGI test, demonstrating typical grammatical development. However, as expected, participants in the SLI group found the TEGI challenging: Of the 13 remaining children who were eligible for the study, 12 performed significantly below the TEGI criterion score (i.e., below the minimum of 78–85 points, depending on the age level); the remaining participant scored a marginal value. This child was included in the study due to overall low performance in the other assessments.

All participants were then given a nonword repetition/articulation screening. This test was administered in order to ensure children's motor ability to produce the test-relevant sound combinations in nonmorphemic contexts. The importance of carrying out this type of screening when studying morpheme acquisition in children with SLI has previously been demonstrated in a number of studies (Smith-Lock, Leita, Lambert, & Nickels, 2013; Tomas et al., 2015). The test contained 16 nonce words presented in a random order. The endings of the target items matched the inflections of the items used in the experiment (see the Appendix for the full list). For example, nonce words /hɒdʒ/ and /hɒzəz/ were

similar to a consonant–vowel–consonant (CVC) stem plus a third person singular morpheme. The task was administered by the experimenter, who produced the words one by one and then asked the child to repeat them. The answers were audiorecorded and then transcribed in the International Phonetic Alphabet, using perceptual cues. The response was labeled as “correct” if it contained the relevant ending (i.e., the onset consonant or the vowel could be substituted). For example, for the nonce word /mezɪ/, the production [nezɪ] was accepted as “correct,” although the initial consonant was changed. In contrast, the responses [mez] and [medz] were both considered as “errors,” because the consonants of interest did not match the target. For each item, we allowed up to three attempts, with the last one used for scoring. The majority of the forms that required a repetition were those with final consonant clusters. For example, words ending in /zd/ and /dz/ constituted 70% of all repeated attempts for the TD group, and 92% for the SLI group. To meet the inclusion criteria, participants needed to correctly repeat the endings of at least 14 out of 16 items on the screening task (see Appendix). This ensured that the participants in the study had no major articulatory problems. The study then proceeded with the 13 participants with SLI and the 19 TD children who passed all the screening tests.

Stimuli

This study was composed of two experiments: (a) a grammaticality judgment task, where participants were asked to listen and determine which of two speakers “gave a better response,” and (b) an elicited production (“wug”) task, during which the participants were invited to answer a question using the inflected target verb in either the present or past tense.

Both tasks used the same set of nonce verbs, consisting of 12 CVC stems. The choice of nonce verbs for the stimuli was motivated by the fact that children's performance is often affected by lexical frequency. This has been observed for both TD and SLI populations: When learning grammatical morphemes, children have been shown to demonstrate a positive correlation between the frequency of the grammatical form in the speech they hear and the likelihood of its retrieval (Matthews & Theakston, 2006; Oetting & Horohov, 1997; Rispen & De Bree, 2014).

The first consonant in the CVC stem was either a stop (/g/, /k/, /p/, /t/) or a nasal (/n/, /m/), followed by a short vowel and ending in /d/ or /z/. The latter allowed us to minimize the number of stems used in the experiment. For example, the nonce words *ked* and *giz* require a syllabic or a segmental allomorph, depending on the morpheme added (e.g., third person singular, as in /kedz/ vs. /gizəz/, compared with past tense *-ed*, as in /kedəd/ vs. /gizd/). A minimum number of nonce verbs was essential for successfully carrying out the “wug” test: The smaller number of novel verbs decreased the pressure on the children's working memory and phonological storage (Gathercole, 2006), ensuring greater focus on the task. Using the same nonce verb stems for both present and past tense morphemes also allowed us

to explore children’s ability to generalize morphophonological patterns across tense morphemes.

Because previous research has not found any voicing effects on morpheme production for either population (Berko, 1958; Marchman et al., 1999; Oetting & Horohov, 1997; Tomas et al., 2015), this study did not include a comparison between voiceless /s/ (e.g., *She /sɪts/*) and voiced /z/ (e.g., *She /ɹʌnz/*). Instead, we investigated possible differences between voiced segmental allomorphs /z, d/ and syllabic allomorphs /əz, əd/ for both tense morphemes. Comparing the voiced /z/ and /d/ to the syllabic allomorphs /əz/ and /əd/ allowed us to explore the structurally most similar stems, differing only in whether they contain an additional schwa/syllable or not.

We selected 12 CVC stems with medium phonotactic probability and neighborhood density values. The criteria were based on frequencies from Storkel’s study (Storkel, Armbrüster, & Hogan, 2006), where biphone frequency was used as the phonotactic probability estimate indicating the “medium values” across the targets ($M = 0.0031$, $SD = 0.002$). The items’ average neighborhood density was also within “normal limits” ($M = 10.67$, $SD = 5.38$). The values were calculated using the online calculator developed by Storkel and Hoover (2010). See Table 3 for the list of items and their individual phonotactic probability and neighborhood density estimates.

Four native speakers of Australian English, all professional linguists, were familiarized with the full list of nonce words to ensure that these sufficiently differed from real words in Australian English. A few stems that are occasionally used in urban slang (e.g., *pud*, a “lazy, useless, or very weak person”) were included in the final set of items on the grounds that a typical 5-year-old would be unlikely to know them due to their very low frequency. The final set of test items contained only those CVC stems approved by all four native speakers. The stimulus sentences were then recorded by a female native speaker of Australian English, and they were added as sound files to a PowerPoint presentation.

To ensure unambiguous contexts for the stimuli, the 12 nonce verbs were paired with 12 animated pictures of cartoon characters, each performing an action associated with a particular word. For example, one of the cartoons showed a pony carrying a boat on its head, which was called *kedding the boat*. The same clips were used during the familiarization task as well as in both experiments. In each task, the nonce verb stem appeared twice, as in *She keds my boat [every day]* for third person singular -s, and *She kedded my boat [yesterday]* for past tense -ed. Detailed descriptions of the protocols are given below.

Procedure

The tasks were administered over a 20–25-min period in a one-on-one session between the experimenter and the child, and they took place after the preliminary screening assessments. The experiments were carried out in the same block order: familiarization task first, followed by the grammaticality judgment task, and then the “wug” test. Each task had a few practice items, which were not included in the analysis. During the session, the participant was seated in front of a laptop computer in a quiet room. The stimuli were introduced as a set of animated pictures in a PowerPoint presentation. Participants were instructed that they would be asked to play three language games: “I will show you pictures of some monsters doing funny things. Then we will talk about the things they do during three simple games. Before each new game, we will practice for a bit to make sure you understand the rules.” The children were told that during the games, they would speak about “things that happen every day” and “things that happened yesterday.” The stimuli for both target morphemes were presented to every participant. The stimuli within each set were pseudo-randomized, and the order of present versus past tense sets was counterbalanced across participants. The responses were audiorecorded using a digital voice recorder Olympus VN-5500PC or Olympus WS750M (Olympus Imaging Corporation, Tokyo, Japan).

Table 3. Nonce verbs used in the experiment and their phonological characteristics.

Target	Stem vowel (real word example)	Phonotactic probability estimates		Neighborhood density estimates	
		Biphone mean frequencies	Phonotactic probability*	Number of neighbors	Neighborhood density*
giz	/ɪ/ (stick)	.0032	Medium	5	Low
ged	/e/ (vet)	.0024	Medium	16	High
ked		.0031	Medium	19	High
nez		.0014	Low	4	Low
pad	/æ/ (cat)	.0033	Medium	12	Medium
kad		.0085	High	19	High
paz		.0036	Medium	12	Medium
nud	/ə/ (bus)	.0018	Low	6	Low
pud		.0026	Medium	10	Medium
muz		.0041	Medium	9	Medium
tuz		.0028	Medium	12	Medium
goz	/ɔ/ (got)	.0006	Low	4	Low

*Grouping is based on the estimates given in Storkel et al. (2006).

Familiarization Task

We first familiarized the participants with the full list of nonce words to ensure that they would be able to do the task. This involved the repetition of 24 sentences (12 non-word stems with two target morphemes) with the nonce verbs embedded in 4-word utterances, as in *He nads my plates* for the third person singular block and *He nadded my plates* for the past tense block.

The items were introduced in the following manner: First, a slide with an animated picture appeared, and then the experimenter gave a prompt such as, “Look at this monster. What does he do every day? Let’s listen!” and then played the embedded audio file. In general, the participants needed a single attempt for each item. However, in cases when the child failed to give a response, requested a repetition of the prompt, or changed the target stem (e.g., produced /gɪdz/ instead of /gɪzd/), the experimenter introduced the item again. Up to three attempts were allowed, ensuring that all participants had heard and could produce the target nonce verbs correctly. After familiarization, we proceeded to the grammaticality judgment task (perception), and then to the “wug” task (production).

Grammaticality Judgment Task

This task assessed children’s abilities to perceive the presence/absence of the morphemes in obligatory contexts. Each target was presented in a pair of sentences, one grammatical and one ungrammatical, introduced as responses by two cartoon animals to the experimenter’s questions. First, the slide with an animated picture appeared on the computer screen. The experimenter gave a prompt such as, “I showed our animals this picture and said: ‘This happens every day, what does this pony do every day?’” The next slide showed the animals sitting side by side, and the experimenter played the prerecorded audio files, adding “And the foxie said [the first audio played]: ‘*He nezes my pet*’ . . . And the kitten said [the second audio played]: ‘*He nez my pet*’ . . . Who gave a better answer this time?” The participant was then asked to say whose utterance sounded better. The responses were audiorecorded for later analysis. If the participant pointed to the picture instead of saying which of two answers he/she preferred, the response was given as a clarification question by the experimenter (e.g., “So, the kitten or the foxie?”). The stimuli were introduced once, unless the child requested a repetition or could not make the judgment after the first attempt. Although we allowed up to three attempts for each item, none of the participants required more than one repetition, and this occurred in less than 5% of cases.

“Wug” Task

The “wug” task is a classical elicitation method (Berko, 1958) that allows us to explore children’s ability to generalize morphophonological patterns in production. The task involved children answering 12 questions about things that happen every day (for third person singular *-s*) and 12 questions about things that happened yesterday (for past tense *-ed*). The items were paired with the same animated videos and were presented in the following manner:

“Remember this animal? He loves nadding my plates. He does it every day. What does he do every day?” The participant was then expected to give an answer such as, “He nads my plates.” If the child did not produce a full sentence (e.g., gave a response such as *Nad every day*), the experimenter gave an additional prompt such as, “Start with ‘every day’ . . .” or “Tell me the whole thing.” If these attempts to elicit a full sentence (grammatical or ungrammatical) were unsuccessful, the experimenter gave the first few words of the target phrase, as in “Yes, so every day. . .”, after which the child finished the sentence. Up to three attempts to complete the sentence were allowed for each item, and only the final production was included in the analysis.

Analysis

Grammaticality Judgment Task

The audio recordings of the children’s grammaticality judgments were coded as “correct” or “incorrect,” depending on whether the response matched the grammatical sentence. The total number of items was 768: 456 responses from TD children and 312 from the SLI group. For the reliability check, a second transcriber analyzed 12.5% of the data (the responses of two participants from each group). The researchers followed the same protocol and reached 100% agreement in their scoring.

“Wug” Task

Children’s responses were transcribed from the audio recordings. Coding for the presence/absence of a morpheme was done using perceptual cues and, in ambiguous cases, acoustic evidence using *Praat* (Boersma & Weenink, 2014). Children’s productions were coded as “correct” if they contained the appropriate allomorph and “incorrect” in cases of omission. Other incorrect productions, such as (a) partial realizations (e.g., /gez/ instead of /gedz/), (b) overgeneralizations (e.g., /mezɔd/ for /mezɔd/), or (c) metathesis (e.g., /gɪdz/ for /gɪzd/), were excluded from the analysis. Together with the instances of missing values (i.e., when the child skipped an item or gave an unintelligible response), there were 70 excluded items (40 from the TD group and 30 from the SLI group). The final set of data included 698 utterances: 416 responses from the TD children and 282 from the children with SLI. A reliability check, carried out for two TD children and two children with SLI, demonstrated 92% agreement between the transcribers. Those items where there was disagreement were reexamined, and a final decision was reached by consensus.

We predicted that the TD group would outperform the SLI group in both tasks. We also predicted that both groups would find producing syllabic /ɜz/ and /əd/ more challenging than segmental /z/ and /d/. However, we thought the longer durations of the syllabic allomorphs might enhance their perception, making these allomorphs more salient in a grammaticality judgment task.

Results

The perception and production data were analyzed separately due to the differences in the types of tasks. However, for both, we applied generalized linear mixed models (Müller, Harrington, Kleber, & Reubold, 2011): binomial logistic regression with the proportion of correct answers as the response variable, using data in aggregated form. Thus, we started with all main factors as well as two-way interaction terms, and then we started removing nonsignificant interactions one by one, on the basis of their p values. It should be noted that none of the main effects was removed in the model selection process. The models that converged given the amount of available data were compared using Akaike information criterion values (Burnham & Anderson, 2002), and the final model for each data set was selected on the basis of its parsimony and the goodness of fit to the data.

Final models had the same main effects: Allomorph (syllabic vs. segmental), Tense (third person singular *-s* vs. past tense *-ed*), and Group (TD vs. SLI) as fixed effects, and Participant nested in Group as a random effect. In addition, the perception model included a Tense $\times$ Allomorph interaction, and the production model included a Group $\times$ Tense interaction. The statistical analysis was carried out in R, version 3.2.1 (R Core Team, 2015). The outputs of the perception and production models are summarized in Tables 4 and 5, respectively, along with the significance levels (p values), odds ratios (ORs), and 95% confidence intervals for each factor of interest and the relevant interaction. An additional standard diagnostic check for overdispersion was performed by calculating a sum of squared Pearson residuals over the residual degrees of freedom. Both models had acceptable overdispersion values (Anderson, Burnham, & White, 1994): 1.41 for the production, and 1.09 for perception data.

Perception Model

The Group variable had the most robust effect, showing that TD participants were significantly more accurate in their responses overall ($p < .001$, OR = 5.11, 95% CI [2.16, 12.10]). Tense also had a significant effect on children's judgments ($p = .017$), with third person singular *-s* being perceived better than past tense *-ed* (OR = 0.55 for the latter, 95% CI [0.34, 0.90]). As an independent

predictor, Allomorph had a marginal effect on the accuracy of morpheme perception ($p = .076$, 95% CI [0.39, 1.05]). However, there was a significant Allomorph $\times$ Tense interaction ($p = .01$, OR = 2.48, 95% CI [1.24, 4.96]), suggesting that children's abilities to perceive presence/absence of an allomorph depended on the morpheme tested. In particular, when making judgments about past tense *-ed*, participants more often preferred syllabic allomorphs to bare stems. However, for third person singular *-s*, the pattern was reversed, with higher performance on the segmental allomorphs (see Figure 1). As expected, the TD group's responses were above 50%, whereas children with SLI did not significantly differ from chance.

Production Model

This model included the same three main effects, Group, Tense, and Allomorph, and a Group $\times$ Tense interaction (see Table 5). Allomorph had the strongest effect on morpheme production, with syllabic allomorphs being much more problematic ($p < .001$, OR = 0.04, 95% CI [0.03, 0.08]). The significant effect of Tense suggested that, overall, past tense *-ed* was more challenging than third person singular *-s* ($p < .001$, OR = 0.18, 95% CI [0.09, 0.37]). In addition, Group helped to explain the variability in children's scores: As in the perception task, the TD children performed significantly better than their peers with SLI ($p < .001$, OR = 5.67, 95% CI [1.65, 19.51]). Note, the Group $\times$ Tense interaction was significant as well ($p < .001$, OR = 12.98, 95% CI [5.07, 33.25]), suggesting that, when adding past tense *-ed*, TD children performed better than expected. This is shown in Figure 2: Unlike participants with SLI, the TD group performed with similar accuracy on both verbal morphemes.

Discussion

This study explored how 5-year-old children with and without SLI perceive and produce tense morphemes depending on the type of allomorph required. A grammaticality judgment task and a "wug" (elicited production) experiment were used to explore children's ability to generalize both segmental and syllabic allomorphs to nonce verbs inflected for the third person singular *-s* and past tense *-ed*.

Table 4. Perception model: Summary of the generalized linear model output for the typically developing (TD) children and children with specific language impairment (SLI).

Factor (level 1 vs. level 2)	p value	Odds ratio of success (level 1 vs. 2)	95% confidence interval
Group (TD vs. SLI)	< .001*	5.11	[2.16, 12.10]
Tense (past vs. present)	.017*	0.55	[0.34, 0.90]
Allomorph (syllabic vs. segmental)	.076	0.64	[0.39, 1.05]
Tense $\times$ Allomorph	.010*	2.48	[1.24, 4.96]

*Statistically significant values.

Table 5. Production model: Summary of the generalized linear model output for the typically developing (TD) children and children with specific language impairment (SLI).

Factor (level 1 vs. level 2)	<i>p</i> value	Odds ratio of success (level 1 vs. 2)	95% confidence interval
Group (TD vs. SLI)	< .001*	5.67	[1.65, 19.51]
Tense (past vs. present)	< .001*	0.18	[0.09, 0.37]
Allomorph (syllabic vs. segmental)	< .001*	0.04	[0.03, 0.08]
Group × Tense	< .001*	12.98	[5.07, 33.25]

*Statistically significant values.

Although we used two separate models to explore perception and production data, the analysis revealed interesting similarities in children's behaviors. As expected, the TD group showed significantly better performance in both tasks compared with their peers with SLI. However, both groups had greater difficulty adding syllabic allomorphs to verb stems in the production task (e.g., *Every day she /gɪzəz/ my hat*, *Yesterday she /kedəd/ my boat*). A similar pattern was found for the perception task, showing a marginal effect of Allomorph as an independent factor, and a significant interaction for Allomorph × Tense. The Allomorph × Tense interaction also suggested that the greater phonetic content of syllabic allomorphs did not systematically enhance morpheme perception in either group of children: Performance on only the past tense *-ed* morpheme was improved, as shown in Figure 1. In contrast, for the third person singular, participants were more successful when making judgments about segmental allomorphs, as in *She /kedz/ my boat*. This result might seem surprising because children are reported to acquire present tense morphemes a bit earlier than past tense morphemes (Brown, 1973). However, our corpus search examining child-directed speech showed that syllabic allomorphs constitute 5% (35 out of 698 total cases) of the third person input children hear, but only 17% (79 out of

467) of past tense *-ed* forms (Tomas et al., 2015). Thus, the higher perception scores for syllabic /əd/ could result from this allomorph's higher overall frequency in the input children hear compared with the present /əz/. However, our findings are consistent with recent infant eye-tracking data showing earlier sensitivity to segmental compared with syllabic inflectional morphology: Davies et al. showed that 2-year-old children can perceive plural /s/ (though not /z/) on the ends of novel words (Davies et al., 2017a), but their other study showed that robust sensitivity to /əz/ plurals is only achieved by 3 years, not yet at 2;6 (Davies, Xu Rattanasone, & Demuth, 2017b). This again suggests that syllabic allomorphs afford no perceptual advantage.

In the production model, we also observed a significant effect for the Group × Tense interaction. Thus, although the TD participants produced segmental allomorphs of both morphemes with similar accuracy, productively adding syllabic /əz/ was significantly more problematic than adding syllabic /əd/. This is despite the fact that our articulatory screening test ensured children's ability to "produce" such forms (see Appendix). However, this may result from design limitations rather than be suggestive of a deviance of the SLI group. In particular, because the delay in language development often occurs on multiple levels (e.g.,

Figure 1. Proportion of segmental versus syllabic third person singular *-s* and past tense *-ed* allomorphs correctly judged as grammatical by specific language impairment (SLI) and typically developing (TD) populations.

Figure 2. Proportion of segmental versus syllabic third person singular -s and past tense -ed allomorphs correctly produced by specific language impairment (SLI) and typically developing (TD) populations.

phonology, grammatical morphology, vocabulary size, etc.), the interaction of these levels may significantly constrain children's overall language skills. Therefore, if a child lags behind in acquiring the sound system as well as the grammatical morphology of their first language, learning morphophonological rules is likely to be even further delayed due to the joint effect of the deficits in each language domain.

This then raises the question of what kind of exposure to different allomorphs is required for learning to take place. Perhaps there is some threshold of total accumulated frequency that a learner must hear to posit a new morphophonological rule (Legate & Yang, 2007). Mirković and Gaskell (2016) showed, using models of lexical learning, that morphological generalization takes place when alternations are systematic. It would be interesting to push this further to explore how learning is affected under different types of type/token frequency distributions.

However, the rules for forming English syllabic morphemes are systematic, and yet generalization is delayed. Perhaps the morphophonological processes that govern them, which prohibit similar linguistic units (tones, segments) being adjacent to each other (e.g., as in *bus*+*/s/*), are not fully transparent. This rule (or constraint), called the obligatory contour principle, mandates that these similar consonants cannot occur adjacent to each other (Leben, 1973; Prince & Smolensky, 2004), and therefore insertion of the default vowel schwa is required to break them up, resulting in a syllabic morpheme (e.g., *bus*+*/əz/*). Perhaps learners have not yet learned this morphophonological constraint, which may have a somewhat different status in children's grammars compared with that of the more common voicing assimilation processes found in English (for discussion of obligatory contour principle effects on the acquisition of tone, see Demuth, 1993).

Another possible explanation for the later acquisition of syllabic morphemes might be that the high frequency of the segmental allomorphs (95% of third person

singular morphemes) has saturated the learning space, allowing learners to assume that syllabic forms are "noise" in the signal until they are introduced to the orthographic form through reading around the age 6 or 7 years. As an alternative, Berko (1958) suggested that children might think that forms such as "bus" were already inflected. This is certainly the case with the past tense of "hit." This interpretation might be reached as in the case of the principle of contrast (Clark, 1987, *inter alia*), where one form is mapped uniquely to one semantic function (see also Slobin's operating principles; Slobin, 1973). If the segmental forms of tense inflection account for 95% of the verb inflections a learner hears, it could be easy to assume that the remainder is irrelevant. Thus, positing another morphological process to account for only a minimal amount of data might come at a high cost, especially if the phonological rule is not found elsewhere in the grammar.

If the acquisition of syllabic morphemes takes a long time to learn for TD children, perhaps it is not surprising that learning these morphophonological alternations would be especially delayed in children with SLI. Recall that Marshall and van der Lely (2007) found that their participants with grammatical SLI, who were 9–16 years old, were not using productive past tense marking for "regular" past tense when it occurred in a complex consonant cluster. It is therefore not clear when and how children with SLI eventually learn to use syllabic inflections productively.

These findings have important implications for morphological learning across languages. Although systematicity and predictability are essential to learning morphophonological alternations, the relative frequency of different "regular" inflections may play a critical role in how and when they are learned. This suggests that models of morphophonological learning must also consider different types of frequency effects to more fully understand how language is learned.

Conclusion

This article explored the ability of 5-year-old TD children and children with SLI to generalize segmental and syllabic morphophonological patterns to novel verbs during perception/grammaticality judgment and elicited production tasks. It was predicted that perception of the syllabic /əz/ and /əd/ might be facilitated by their longer durations and hence greater perceptual salience. At the same time, these allomorphs are much less frequent in child-directed speech, probably contributing to the reported later mastery of these allomorphs in production. The latter was confirmed: Although the TD children performed better overall on both tasks, they scored poorly at producing syllabic allomorphs, and their peers with SLI produced hardly any of these forms (< 7.5% on average). However, in grammaticality judgment tasks involving past tense *-ed*, the TD group showed slightly better perception of syllabic compared with segmental allomorphs. This might be due to the higher frequency of the syllabic /əd/ past tense allomorphs compared with the syllabic /əz/ present tense forms in child-directed speech. Therefore, these findings suggest that acquisition of morphophonological patterns involving low-frequency allomorphs is still underway in TD children at 5 years of age, and is even more protracted in SLI populations, despite the high predictability of these patterns. Even by the age of 6, TD children cannot consistently generalize the regular morphophonological patterns of English in present and past tense (see Figure 2). This suggests that it may be the frequency of the pattern (i.e., the allomorph), rather than its systematicity/regularity, that has the greater effect on children's ability to generalize it.

The SLI group showed similar patterns of development to that of their TD peers (albeit with lower overall performance), so this suggests that these children are delayed rather than deviant in their linguistic development. However, due to their protracted pattern-finding when learning morphophonological rules, they are likely to benefit from targeted intervention for these forms, i.e., by having an increased proportion of the low-frequency allomorphs among practice items.

Understanding the processes underlying the acquisition of morphophonological alternations has important theoretical implications for understanding grammatical development. Thus, the term “acquired” might be more appropriate when a child consistently uses all allomorphs and is able to generalize this knowledge to novel forms. This should also be helpful for developing testing procedures for assessing a child's understanding of the target grammar cross-linguistically.

Acknowledgments

This research was supported by funding from Macquarie University, the Australian Research Council (ARC) Centre of Excellence in Cognition and its Disorders (Grant CE110001021, awarded to Crain et al.), and ARC Grant FL130100014, awarded to Katherine Demuth. We especially thank the ARC Centre of Excellence in Cognition and its Disorders for its additional financial support, and North East Metropolitan Language Development

Centre and its staff for their help in organizing the testing on site in Perth. We are very grateful to Jeanette Morley, Sandra Gerbaz, Robert Wells, Kelly Miles, Gretel Macdonald, and Amy German for their participation in the project, to Elaine Schmidt for her assistance and comments on the manuscript, and to the staff and students of the Child Language Laboratory at Macquarie University for their helpful feedback.

References

- Anderson, D. R., Burnham, K. P., & White, G. C. (1994). AIC model selection in overdispersed capture-recapture data. *Ecology*, 75, 1780–1793.
- Berko, J. (1958). The child's learning of English morphology. *Word*, 14, 150–177.
- Bishop, D. V. M., & Norbury, C. F. (2008). Speech and language impairments. In M. Rutter, D. V. M. Bishop, D. S. Pine, S. Scott, J. Stevenson, E. Taylor, & A. Thapar (Eds.), *Child and adolescent psychiatry* (5th ed., pp. 782–801). Oxford, United Kingdom: Blackwell.
- Boersma, P., & Weenink, D. (2014). *Praat: Doing phonetics by computer* [Computer program]. Version 5.4.01. Retrieved from <http://www.praat.org/>
- Brown, R. (1973). *A first language: The early stages*. Cambridge, MA: Harvard University Press.
- Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multi-model inference: A practical information-theoretic approach* (2nd ed.). New York, NY: Springer-Verlag.
- Clark, E. V. (1987). The principle of contrast: A constraint on language acquisition. In B. MacWhinney (Ed.), *Mechanisms of language acquisition* (pp. 1–33). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Clark, E. V. (2003). *First language acquisition*. New York, NY: Cambridge University Press.
- Cleave, P., & Rice, M. (1997). An examination of the morpheme BE in children with specific language impairment: The role of contractibility and grammatical form class. *Journal of Speech, Language, and Hearing Research*, 40, 480–492.
- Conti-Ramsden, G., & Botting, N. (1999). Classification of children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, 42(5), 1195–1204. <https://doi.org/10.1044/jslhr.4205.1195>
- Davies, B., Xu Rattansone, N., & Demuth, K. (2017a). Two-year-olds' sensitivity to inflectional plural morphology: Allomorphic effects. *Language Learning and Development*, 13(1), 38–53. <https://doi.org/10.1080/15475441.2016.1219257>
- Davies, B., Xu Rattanasone, N., & Demuth, K. (2017b). *Three-year-olds' understanding of the syllabic plural allomorph /əz/*. Manuscript submitted for publication.
- Demuth, K. (1993). Issues in the acquisition of the Sesotho tonal system. *Journal of Child Language*, 20(2), 275–301.
- Demuth, K. (2014). Prosodic licensing and the development of phonological and morphological representations. In A. Farris-Trimble & J. Barlow (Eds.), *Perspectives on phonological theory and acquisition: Papers in honor of Daniel A. Dinnsen* (pp. 11–24). Language Acquisition and Language Disorders Series 56. Amsterdam, the Netherlands: John Benjamins.
- Demuth, K., Culbertson, J., & Alter, J. (2006). Word-minimality, epenthesis, and coda licensing in the acquisition of English. *Language & Speech*, 49, 137–174.
- de Villiers, J. G., & de Villiers, P. A. (1973). A cross-sectional study of the acquisition of grammatical morphemes in child speech. *Journal of Psycholinguistic Research*, 2(3), 267–278. <https://doi.org/10.1007/BF01067106>

- Dube, S., Kung, C., Peter, V., Brock, J., & Demuth, K. (2016). Effects of sentence position and type of violation on the auditory processing of subject-verb agreement: An auditory ERP study. *Frontiers in Psychology*, 7, 1276. <https://doi.org/10.3389/fpsyg.2016.01276>
- Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics*, 27, 513–543. <https://doi.org/10.1017/S0142716406060383>
- Goad, H. (1998). Plurals in SLI: Prosodic deficit or morphological deficit?. *Language Acquisition*, 7(2–4), 247–284. https://doi.org/10.1207/s15327817la0702-4_6
- Goldberg, A. (2006). *Constructions at work: The nature of generalization in language*. Oxford, United Kingdom: Oxford University Press.
- Grijzenhout, J., & Penke, M. (2005). On the interaction of phonology and morphology in language acquisition and Broca's aphasia: The case of inflected verbs. In G. Booij & J. van Marle (Eds.), *Yearbook of morphology* (pp. 49–81). Berlin, Germany: Springer.
- Harrington, J., Cox, F., & Evans, Z. (1997). An acoustic phonetic study of broad, general, and cultivated Australian English vowels. *Australian Journal of Linguistics*, 17(2), 155–184. <https://doi.org/10.1080/07268609708599550>
- Jolly, H. R., & Plunkett, K. (2008). Inflectional bootstrapping in 2-year-olds. *Language and Speech*, 51(1&2), 45–59.
- Kager, R., van der Feest, S., Fikkert, P., Kerkhoff, A., & Zamuner, T. (2007). Representations of [voice]: Evidence from acquisition. *Amsterdam Studies in the Theory and History of Linguistic Science Series*, 286(4), 41–80.
- Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test—Second Edition*. Bloomington, MN: Pearson, Inc.
- Kerkhoff, A. (2003). Acquisition of voicing alternations. In J. van Kampen & S. Baauw (Eds.), *Proceedings of GALA 2003 (Generative Approach to Language Acquisition): Vol. 2* (pp. 269–280). Utrecht, the Netherlands: Landelijke Onderzoeksschool Taalwetenschap.
- Kerkhoff, A. (2007). *Acquisition of morpho-phonology: The Dutch voicing alternation*. Utrecht, the Netherlands: University of Utrecht, Landelijke Onderzoeksschool Taalkunde.
- Kernan, K. T., & Blount, B. G. (1966). The acquisition of Spanish grammar by Mexican children. *Anthropological Linguistics*, 8(9), 1–14.
- Leben, W. (1973). *Suprasegmental phonology* (Doctoral dissertation). Retrieved from Indiana University Linguistics Club.
- Legate, J. A., & Yang, C. (2007). Morphosyntactic learning and the development of tense. *Language Acquisition*, 14(3), 315–344.
- Leonard, L. B. (1998). *Children with specific language impairment*. Cambridge, MA: MIT Press.
- Leonard, L. B. (2016). Noun-related morphosyntactic difficulties in specific language impairment across languages. *First Language*, 36(1), 3–29. <https://doi.org/10.1177/0142723715626070>
- Leonard, L. B., Deevy, P., Miller, C. A., Rauf, L., Charest, M., & Robert, K. (2003). Surface forms and grammatical functions: Past tense and passive participle use by children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, 46(1), 43–55.
- Leonard, L. B., Eyer, J. A., 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(4), 741–753.
- Levelt, C. C., Schiller, N.O., & Levelt, W. J. (2000). The acquisition of syllable types. *Language Acquisition*, 8, 237–264.
- Marchman, V. A., Wulfeck, B., & Weismer, S. E. (1999). Morphological productivity in children with normal language and SLI: A study of the English past tense. *Journal of Speech, Language, and Hearing Research*, 42, 206–220.
- Marshall, C. R., Harcourt-Brown, S., Ramus, F., & van der Lely, H. K. J. (2009). The link between prosody and language skills in children with specific language impairment (SLI) and/or dyslexia. *International Journal of Language & Communication Disorders/Royal College of Speech & Language Therapists*, 44(4), 466–88. <https://doi.org/10.1080/13682820802591643>
- Marshall, C. R. & van der Lely, H. K. J. (2007). The impact of phonological complexity on past tense inflection in children with grammatical-SLI. *Advances in Speech-Language Pathology*, 9(3), 191–203. <https://doi.org/10.1080/14417040701261509>
- Matthews, D. E., & Theakston, A. (2006). Errors of omission in English-speaking children's production of plurals and the past tense: The effects of frequency, phonology, and competition. *Cognitive Science*, 30, 1027–1052.
- Mealings, K. T., Cox, F., & Demuth, K. (2013). Acoustic investigations into the delayed acquisition of the syllabic -es plural in 2-year-olds' speech. *Journal of Speech, Language, and Hearing Research*, 56, 1260–1271.
- Mirković, J., & Gaskell, G. (2016). Does sleep improve your grammar? Preferential consolidation of arbitrary components of new linguistic knowledge. *PLoS One*, 11(4), e0152489.
- Müller, V., Harrington, J., Kleber, F., & Reubold, U. (2011). Age-dependent differences in the neutralization of the intervocalic voicing contrast: Evidence from an apparent-time study on East Franconian. In *Proceedings of the 12th Annual Conference of the International Speech Communication Association 2011 (INTERSPEECH 2011): Vol. 1* (pp. 640–643). Red Hook, NY: Curran Associates.
- Oetting, J. B., & Horohov, J. E. (1997). Past-tense marking by children with and without specific language impairment. *Journal of Speech, Language, and Hearing Research*, 40, 62–75.
- Polite, E. J. (2011). The contribution of part-word phonological factors to the production of regular noun plural -s by children with and without specific language impairment. *First Language*, 31(4), 425–441. <https://doi.org/10.1177/0142723711406431>
- Prince, A., & Smolensky, P. (2004). *Optimality theory: Constraint interaction in generative grammar*. Malden, MA: Blackwell.
- R Core Team. (2015). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from <http://www.R-project.org/>
- Ramus, F., Marshall, C. R., Rosen, S., & van der Lely, H. K. J. (2013). Phonological deficits in specific language impairment and developmental dyslexia: Towards a multidimensional model. *Brain*, 136(2), 630–645. <https://doi.org/10.1093/brain/aww356>
- Rice, M. L., Tomblin, J. B., Hoffman, L., Richman, W. A., & Marquis, J. (2004). Grammatical tense deficits in children with SLI and nonspecific language impairment. *Journal of Speech, Language, and Hearing Research*, 47(4), 816–834. [https://doi.org/10.1044/1092-4388\(2004/061\)](https://doi.org/10.1044/1092-4388(2004/061))
- Rice, M. L., & Wexler, K. (1996). Toward tense as a clinical marker of specific language impairment in English-speaking children. *Journal of Speech and Hearing Research*, 39, 1239–1257.
- Rice, M. L., & Wexler, K. (2001). *Test of Early Grammatical Impairment*. New York, NY: The Psychological Corporation: A Harcourt Assessment Company. Retrieved from http://www2.ku.edu/~cldp/MabelRice/screener_pack/
- Rice, M. L., Wexler, K., & Cleave, P. L. (1995). Specific language impairment as a period of extended optional infinitive. *Journal of Speech and Hearing Research*, 38, 850–863.

- Rispens, J. E., & De Bree, E. H.** (2014). Past tense productivity in Dutch children with and without SLI: The role of morphophonology and frequency. *Journal of Child Language*, 41(1), 200–225. <https://doi.org/10.1017/S0305000912000542>
- Roark, B., & Demuth, K.** (2000). Prosodic constraints and the learner's environment: A corpus study. In S. C. Howell, S. A. Fish, & T. Keith-Lucas (Eds.), *Proceedings of the 24th Annual Boston University Conference on Language Development* (pp. 597–608). Somerville, MA: Cascadilla Press.
- Royle, P., & Stine, I.** (2013). The French noun phrase in pre-school children with SLI: Morphosyntactic and error analyses. *Journal of Child Language*, 40(5), 945–970. <https://doi.org/10.1017/S0305000912000414>
- Slobin, D. I.** (1973). Cognitive prerequisites for the development of grammar. In C. A. Ferguson & D. I. Slobin (Eds.), *Studies of child language development* (pp. 240–249). New York, NY: Holt Rinehart & Winston.
- Smith-Lock, K. M., Leita, S., Lambert, L., & Nickels, L.** (2013). Effective intervention for expressive grammar in children with specific language impairment. *International Journal of Language & Communication Disorders/Royal College of Speech & Language Therapists*, 48(3), 265–282. <https://doi.org/10.1111/1460-6984.12003>
- Song, J. Y., Demuth, K., Evans, K., & Shattuck-Hufnagel, S.** (2013). Durational cues to fricative codas in 2-year-olds' American English: Voicing and morphemic factors. *The Journal of the Acoustical Society of America*, 133, 2931–2946.
- Song, J. Y., 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.
- Storkel, H. L., Armbrüster, J., & Hogan, T. P.** (2006). Differentiating phonotactic probability and neighborhood density in adult word learning. *Journal of Speech, Language, and Hearing Research*, 49(6), 1175–1192. [https://doi.org/10.1044/1092-4388\(2006/085\)](https://doi.org/10.1044/1092-4388(2006/085))
- Storkel, H. L., & Hoover, J. R.** (2010). An on-line calculator to compute phonotactic probability and neighborhood density based on child corpora of spoken American English. *Behavior Research Methods*, 42(2), 497–506.
- Sundara, M., Demuth, K., & Kuhl, P.** (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.
- Theodore, R., 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, 539–549. [https://doi.org/10.1044/1092-4388\(2010/10-0035\)](https://doi.org/10.1044/1092-4388(2010/10-0035))
- Theodore, R., Demuth, K., & Shattuck-Hufnagel, S.** (2012). Segmental and positional effects on children's coda production: Comparing evidence from perceptual judgments and acoustic analysis. *Clinical Linguistics & Phonetics*, 26(9), 755–773.
- Theodore, R., Demuth, K., & Shattuck-Hufnagel, S.** (2015). Examination of the locus of positional effects on children's production of plural –s: Considerations from local and global speech planning. *Journal of Speech, Language, and Hearing Research*, 58, 946–953.
- Tomas, E., Demuth, K., Smith-Lock, K. M., & Petocz, P.** (2015). Phonological and morphophonological effects on grammatical development in children with specific language impairment. *International Journal of Language & Communication Disorders*, 50(4), 516–528. <https://doi.org/10.1111/1460-6984.12152>
- Tomasello, M.** (2003). *Constructing a language: A usage-based theory of language acquisition*. Cambridge, MA: Harvard University Press.
- Tomasello, M.** (2009). The usage-based theory of language acquisition. In E. L. Bavin (Ed.), *The Cambridge handbook of child language* (pp. 69–87). Cambridge, UK: Cambridge University Press.
- van de Vijver, R., & Baer-Henney, D.** (2011). Acquisition of voicing and vowel alternations in German. In N. Danis, K. Mesh, & H. Sung (Eds.), *The 35th Boston University Conference on Language Development* (pp. 603–615). Somerville, MA: Cascadilla Press.
- van de Vijver, R., & Baer-Henney, D.** (2012). Voice more, front less: On the development of knowledge of voicing and vowel alternations in German nouns by 5 year-olds, 7 year-olds and adults. In A. Biller, E. Chung, & A. Kimbal (Eds.), *The 36th Boston University Conference on Language Development* (pp. 660–672). Somerville, MA: Cascadilla Press.
- van de Vijver, R., & Baer-Henney, D.** (2013). On the development of the productivity of plural suffixes in German. In S. Baiz, N. Goldman, & R. Hawkes (Eds.), *The 37th Annual Boston University Conference on Language Development* (pp. 444–455). Somerville, MA: Cascadilla Press.
- Wexler, K.** (1994). Optional infinitives, head movement and the economy of derivations. In D. Lightfoot & N. Hornstein (Eds.), *Verb movement* (pp. 305–350). Cambridge, United Kingdom: Cambridge University Press.
- Wiig, E., Secord, W., & Semel, E.** (2006). *Clinical Evaluations of Language Fundamentals Preschool–2nd Edition–Australian and New Zealand Editions*. San Antonio, TX: Psychological Corporation.
- Zamuner, T. S., & Johnson, E. K.** (2011). Methodology in phonological acquisition: Assessing the joint development of speech perception and production. In B. Botma, N. Kula, & K. Nasukawa (Eds.), *Continuum handbook to phonology* (pp. 16–29). Amsterdam, the Netherlands: Continuum. Retrieved from https://www.utm.utoronto.ca/infant-child-centre/sites/files/infant-child-centre/public/shared/elizabeth-johnson/Zamuner_Johnson_handbook.pdf
- Zamuner, T. S., Kerkhoff, A., & Fikkert, P.** (2011). Phonotactics and morphophonology in early child language: Evidence from Dutch. *Applied Psycholinguistics*, 33(3), 481–499. <https://doi.org/10.1017/S0142716411000440>

Appendix

Items Presented During a Nonword Repetition Screening of Articulation Skills

1. Imitating the stem + third person singular -s context:
 - a) consonant–consonant sequence: /hɒdz/, /vɪdz/, /tædz/, /kɒdz/;
 - b) consonant–schwa–consonant sequence: /hɒzəz/, /læzəz/, /dezəz/, /ɪzəz/.
 2. Imitating the stem + past tense -ed context:
 - a) consonant–consonant sequence: /bɪzd/, /kæzd/, /mezd/, /dɒzd/;
 - b) consonant–schwa–consonant sequence: /hɒdəd/, /tɒdəd/, /lædəd/, /vɪdəd/.
-