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Accounting for variability in 2-year-olds' production of coda consonants

Cecilia Kirk and Katherine Demuth

University of Canterbury and Brown University

Contact address:

Cecilia Kirk
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch 8020
New Zealand
Email: cecilia.kirk@canterbury.ac.nz

Katherine Demuth
Department of Cognitive & Linguistic Sciences
Brown University
Box 1978
Providence, RI 02912
USA
Email: Katherine_Demuth@brown.edu

Abstract

One of the challenges in child language research is determining when children have acquired a particular linguistic structure, and of particular interest is the identification of factors that contribute to variable performance. The purpose of the current study was to better understand the mechanisms underlying children's variable production of syllable-final (coda) consonants (e.g., *dog*). Fifteen two-year-olds were asked to imitate novel words of different phonological shapes. Production accuracy was assessed by comparing coda consonant production in stressed vs. unstressed syllables, in word-medial vs. word-final syllables, in monosyllabic vs. bisyllabic words, and also stop codas vs. nasal codas. Children were most accurate at producing codas in monosyllables, and least likely to produce codas in medial unstressed syllables, with no systematic segmental effects. Because existing data cast doubt on purely perceptual accounts of the role of acoustic prominence, we argue that the longer durations of acoustically prominent syllables provide learners with more time to articulate coda consonants, thereby enhancing production accuracy. The paper concludes with a discussion of the larger implications of variability in phonological development.

Introduction

One of the longstanding issues in the study of language development has been how to handle within-speaker variability. Previous research has shown significant within-child variability in early word productions (e.g., Vihman, 1993). For example, the same child may produce some word-final (coda) consonants but not others (e.g., Kehoe & Stoel-Gammon, 2001; Stites, Demuth & Kirk, 2004). Although various perceptual, production, frequency-based, and phonological proposals have been offered to account for this type of within-subject variability (cf. Ferguson, Menn & Stoel-Gammon, 1992), many issues regarding children's knowledge of linguistic structure, and the factors contributing to their variable performance, are yet to be fully addressed. This is important not only for understanding processes of normal acquisition, but also for addressing issues of language delay.

Over the past fifteen years, researchers have increasingly begun to examine children's acquisition of syllable and word structures. Some of this research indicates that the segments, syllable structures, and word structures found in children's early speech tend to exhibit 'unmarked', simple structures (cf. Jakobson 1948/61). Fikkert (1994) showed that children learning Dutch initially produce 'core' CV syllable shapes rather than more complex CVC syllable structures containing a syllable-final coda consonant (e.g., *dog* /dag/ → ['da], ['dada]). These insights have been formalized in terms of a constraint-satisfaction problem within Optimality Theory (Prince & Smolensky, 2004), where children's early grammars were proposed to have a constraint against syllable-final (coda) consonants (e.g., Demuth, 1995; Gnanadesikan, 2004). This constraint is often active (highly ranked) in young children's grammars, rapidly becoming less so (more lowly ranked) in languages like English where coda consonants abound. However, this perspective on early grammars also makes the prediction that once children can

produce more complex syllable structures containing coda consonants, they should be able to produce codas in any position within a word, all else being equal. Of course, all else is never completely equal, and we do find variability in a child's production of coda consonants in different contexts.

Several studies have shown that stress and position within the word may facilitate children's production of consonants. Stressed syllables in English are of higher pitch, longer duration and have stronger amplitude than unstressed syllables (Lehiste, 1970). Similarly, word-final syllables contain more salient acoustic cues than syllables in word-medial position, with lengthening occurring in final position (Cooper, 1983). This lack of acoustic prominence on unstressed, non-final syllables may contribute to their being perceived inaccurately, or not at all. Klein (1981) has shown that the two children in her study (aged 1;8 to 1;11) tended to produce consonants in stressed syllables more accurately than in unstressed syllables. There was also an effect of position within the word such that when a final unstressed syllable was preceded by another unstressed syllable, as in *animal*, the final syllable was more likely to be accurately produced, suggesting that these acoustically prominent positions facilitate production. Echols and Newport (1992) report similar findings. In spontaneous data collected from three children aged 1;5 to 1;11, consonants in stressed or final syllables were produced more accurately than consonants in unstressed, non-final syllables. They propose that these positions are privileged for segmental accuracy because stressed and final positions are perceptually more salient, presumably enhancing the perceptual encoding of these syllables and subsequent lexical access and production. However, although the studies by both Klein (1981) and Echols and Newport (1992) show an effect of acoustic prominence on segmental accuracy, neither gives a breakdown of children's production accuracy according to where in the syllable the consonant occurred. We,

therefore, do not know if acoustic prominence primarily affects the production of syllable onsets (consonants at the beginnings of syllables – e.g., *dog* /dag/), or if it also influences children's production of syllable codas (consonants at the end of syllables, e.g., *dog* /dag/g).

Schwartz and Goffman (1995) investigated the effect of stress and position within the word on the segmental production accuracy of syllable onsets. They asked children aged 1;10 to 2;4 to imitate novel words of the shape CVCV, such as ['gæbi] and [gæ'bi], and found that unstressed syllables were much more likely to be omitted, particularly at the beginning of words. However, when deletions due to syllable omissions were excluded, consonant errors in the remaining syllable were not affected by stress or position within the word.

One recent study has specifically considered the role of acoustic prominence on the production of coda consonants. Zamuner and Gerken (1998) looked at the effect of stress environment on coda production in word-final position. Using a novel word imitation task, they found that English-speaking two-year-olds were more likely to delete word-final codas in unstressed syllables than in stressed syllables. However, this study did not investigate the effects of position within the word on coda production.

There have been a number of longitudinal studies which investigate the effect of position within the word on coda production. Studies in Dutch (Fikkert, 1994) and French (Rose, 2000) have shown that word-medial codas are acquired later than word-final consonants. Given these crosslinguistic findings, we might expect that children learning English would also be less accurate at producing codas in medial position.

Other studies have shown that the length of the word in which a consonant is embedded may affect its likelihood of being produced accurately. It has been noted that there is an inverse relationship between the number of syllables in a word and the length of the stressed syllable

(Ladefoged, 1993; Lehiste, 1972; Port, 1981). For example, compare the length of the monosyllabic word *speed*, with the initial syllable of *speedy*, and *speedily*. Notice that the duration of *speed* reduces as the number of syllables in the word increases. We might then expect that coda consonants in monosyllables will be acoustically more salient due to their slightly longer duration than coda consonants in bisyllables. Children with functional articulation problems (aged 4;8 – 6;8) have been shown to produce more errors when attempting word-final codas in bisyllabic words than in monosyllabic words, although this effect only approached significance (Panagos, Quine, & Klich, 1979). One confound in this study is that the majority of the bisyllabic test items ended with an unstressed syllable while the monosyllabic words were all stressed, thus word length was confounded with stress. It remains to be seen whether normally developing children who are acquiring their first words will make more errors in producing word-final codas in bisyllables if these codas are all in stressed syllables.

It has also been suggested that sonority influences coda production. Fikkert (1994) reports that children learning Dutch produce obstruent codas (stops, affricates, and fricatives) before sonorant codas (nasals and liquids), at least in stressed monosyllabic words. However, this pattern of coda acquisition does not seem to hold for English. Kehoe & Stoel-Gammon (2001) find that the order of acquisition in English is typically voiceless stops, followed by voiceless fricatives and nasals, then voiced obstruents, and finally liquids. Zamuner (1996), using longitudinal data collected from one child learning English (Smith, 1973), found that sonorant codas were produced before obstruent codas in unstressed syllables. Similarly, in an experimental study, Zamuner and Gerken (1998) found that in unstressed syllables, word-final obstruents were more likely to be deleted than word-final sonorants. However, it is not clear

whether this preference for sonorants in word-final unstressed syllables also holds in word-medial position.

This review of the literature suggests that some of the variability in the production of coda consonants may be due to stress, position within the word, word-length, and sonority. However, these factors have not been examined together in a controlled manner. To establish how well each of these factors accounts for variability in coda production, we conducted an experimental study where we systematically compared accuracy of coda production in stressed vs. unstressed syllables, in final vs. medial position, in monosyllables vs. bisyllables, and when codas were nasals vs. stops.

Study 1: Coda Production in Novel Words

Method

Participants. Because this study was designed to investigate coda production in phonologically complex contexts, we wanted to ensure that participants could produce codas in known, monosyllabic words. All participants were therefore screened using a warm-up picture-identification task where they were required to spontaneously produce at least half of the 18 familiar monosyllabic words with singleton codas (e.g. *dog, cat, etc.*). Performance on this task, rather than age, vocabulary size, or grammatical development (e.g., MLU (mean length of utterance)) was deemed a more appropriate measure of phonological competence for the purposes of this study.

Twenty-six children were recruited to participate in the word production study. Eleven of these children failed to complete the study and their data were not included in the final analysis. Of these, 3 did not respond to at least half the items in a screening warm-up task. A further 2 children responded to the majority of items in the warm-up task, but did not reliably produce

singleton codas. The novel word task was not administered to these five children. An additional 6 children produced codas in the warm-up task, but did not respond to at least half the test items in the novel word task. This high attrition rate was probably due to the complexity of the demanding novel word-production task, where all test items were unfamiliar words paired with unfamiliar objects, and the majority of test items were bisyllabic with complex syllable structure. The 15 children (10 females, 5 males) who completed the task ranged in age from 1;7 to 2;6 (mean = 2;2). Five children were tested in Auckland, New Zealand and 10 were tested in Providence, RI, USA. All children were from English-speaking monolingual homes. Given that both dialects of English lack post-vocalic [ɹ], we did not include this consonant in our materials. Data analysis showed no difference between groups, so data from the two groups were combined for all further analyses.

As our baseline measure of phonological competence, we used the production accuracy of codas in the monosyllabic CVC novel test items. Overall production of codas in the monosyllabic CVC test items by all 15 children who completed the study was very accurate (93%), with only 7% of responses to monosyllabic test items containing coda production errors of deletion or substitution. Given that a child could reliably produce codas in the monosyllabic CVC novel test items, we then wanted to know whether she could also produce these same coda consonants in bisyllabic words, and if there would be any effect of stress (stressed vs. unstressed syllables), position within the word (word-medial vs. word-final syllables), or sonority (stop codas vs. nasal codas).

It should be noted that the children who were able to complete this rather difficult task were probably at the upper end of the normal spectrum of phonological ability for their age. Thus, their performance on the task may not accurately represent what can be expected of

children between the ages of 1;7 and 2;6. However, although the children in our study were likely to be more phonologically advanced than their age-mates, we assume that similar patterns of production will be found in children who develop more slowly, but within normal limits.

Materials. The purpose of this study was to investigate the effect of different phonological contexts on children's production of a subset of English coda consonants. We therefore wanted to examine children's production of the same consonants in different environments rather than compare production of all the possible coda consonants of English. We initially restricted the stimuli to stop, nasal, and liquid codas. We did not include fricative codas because these segments are often later acquired, and including them would have increased the number of test items such that it would have been difficult to complete in a single session. We also excluded /t/ and /d/ to avoid possible morphological confounds.

The stimuli consisted of 35 novel words (see Appendix). Seven different consonants appeared in coda position: /p,b,k,g,m,n,l/. All other consonants (i.e., those in syllable onset position) were stops or nasals, because these consonants are the earliest acquired and so are the least likely to cause errors in production. All vowels were lax, which should encourage coda production because in English, stressed syllables with a lax vowel must be closed by a consonant. There were 5 different word shapes, each containing one or two target codas (underlined): (i) monosyllabic ('CVC), (ii) iambic with a single medial consonant (CV'CVC), (iii) trochaic with a single medial consonant ('CVCVC), (iv) iambic with a medial cluster (CVC.'CVC), (v) trochaic with a medial cluster ('CVC.CVC). All medial clusters were separated by a phonotactically-determined syllable boundary (e.g., ['gɛp.nək]). Note that only word-final consonants were analyzed as codas in CVCVC words, but both medial and final codas in

CVC.CVC words were analyzed. Each of the 5 word shapes occurred with the 7 coda consonants, yielding a total of 35 test items. Each novel word was paired with a computer-generated picture of a novel shape (see <http://www.cog.brown.edu/~tarr/stimuli.html>).

One of the questions that arises is what constitutes a coda. In this paper, we assume that both word-final consonants (CVC) and word-medial consonants preceding a phonotactically-determined syllable boundary (CVC.CVC) are syllabified as codas. This is a controversial assumption since some researchers have proposed that word-final consonants are syllabified as the onsets of empty-headed syllables (e.g., Harris, 1994; Piggot, 1999). We revisit these representational issues in the final section, but for now we follow the traditional view that word-final consonants are codas.

A second question involves the syllabic status of word-medial singleton consonants (e.g., CVCVC) in children's early speech, a topic that has received much recent acquisition interest (see the special issue of *Clinical Linguistics and Phonetics* edited by Stemberger & Bernhardt, 2002). Stoel-Gammon (2002) has shown that, based on spontaneous productions from 32 normally-developing children at 1;9 and 2;0, intervocalic consonants pattern more like onsets than codas, although some intervocalic consonants, notably fricatives, pattern more like codas. Rvachew and Andrews (2002) investigated the effect of stress on the syllabification of intervocalic consonants in 13 preschool children with phonological delays. Intervocalic consonants directly preceding stressed syllables were produced in the same manner as consonants that were unambiguously onsets. However, intervocalic consonants that occurred before unstressed syllables were produced in the same manner as consonants that were unambiguously codas. Even in adult English, the syllabification of medial consonants following stressed syllables is far from clear. Researchers have variously analyzed these consonants as

onsets (e.g., Grunwell, 1982), as codas (e.g., Hoard, 1971; Selkirk, 1982; Stampe, 1972), and as ambisyllabic (e.g., Kahn, 1976). Given the ambiguous syllabification of word-medial single consonants in the speech of both children learning English and English-speaking adults, we decided not to include these consonants in our study of contextual effects on coda production. We did, however, examine word-final codas in these CVCVC word shapes, thereby providing additional bisyllabic items.

The use of nonsense words allowed us to ensure that none of the participants had heard any of the stimuli before. Using nonsense words also allowed the segmental content of syllables to be matched across phonological contexts. Although it has been suggested that imitative speech may not tap into the child's phonological system in the same way as spontaneous speech, there are numerous results showing that the patterns found in imitation tasks are similar to those found in spontaneous speech. Of particular relevance to the current research is a production study by Kehoe and Stoel-Gammon (2001) which showed no difference in the accuracy of imitated and spontaneous productions of coda consonants by toddlers.

Procedure. Two experimenters visited the participants in their homes or at childcare centers. Each experimental session began with the warm-up task where the participant was asked to identify pictures of real monosyllabic objects containing a singleton coda. Upon successful completion of this task, the first author showed each participant a book containing pictures of computer-generated novel shapes and said, "This is a X. Can you say X?" (where X stands for one of the test items). If the participant did not produce any response, he or she was provided with a second model of the test item. If no response was forthcoming after hearing the test item for a second time, the experimenter moved on to the next test item. All productions of the test items, whether correctly produced or not, were reinforced with praise.

The test items were divided into 2 lists and pseudo-randomized such that related iambic and trochaic forms (e.g., [ˈnɛgəp] vs. [nəˈgɛp]) were in different lists, and no more than two iambic or two trochaic items were presented consecutively. Each child was presented with both lists, half the participants hearing List 1 first and the other half hearing List 2 first. Participants heard both lists on the same day with a 10-minute break between lists. Data analysis showed no significant difference in performance across blocks, nor in order of presentation.

All experimental sessions were digitally recorded with a SONY Mini Disk Walkman MZ-R700 and a SONY ECM-MS907 microphone held within 16 inches of the participant's mouth. The use of spoken novel stimuli (rather than prerecorded or synthetic speech) helped encourage participants to continue with this demanding novel word production task. Later evaluation of the spoken stimuli words showed consistent use of appropriate stress, segmental content, and release of coda consonants.

Data transcription. All data were transcribed off-line by two transcribers using broad phonemic transcription supplemented by diacritics to indicate vowel length and nasalization. Any differences between the two transcribers were re-transcribed by a third transcriber. Transcriptions not agreed on by at least two transcribers were discarded (less than 1% of all responses). One of the transcribers was the first author and all transcribers were experienced in transcribing the speech of young children.

Data analysis. The 5 test items with /l/ in coda position were discarded because of difficulties in determining whether the liquid in these test items had undergone deletion or vocalization. Only the first response to each test item was analyzed. Monosyllabic responses to bisyllabic iambic targets were discarded (N = 55), the initial unstressed syllable being deleted significantly more often in CVCVC words (24%) than in CVC.CVC words (9%) [$t(14) = 4.12, p$

< .001 (2 tailed)]. Responses in which the target iambs were produced as trochees were also discarded (N = 3), as were target trochees that were produced as iambs (N = 5). A total of 508 attempted codas were included in the final analysis. Of this total, 84 were responses to monosyllabic targets. The remaining 424 responses that were analyzed were bisyllabic responses to bisyllabic targets. The mean number of responses per children to the 30 test items analyzed was 28 (range of 21-30).

There were more responses in final than in medial position because there were twice as many test items with codas in final position (both CVCVC‾ and CVC.CVC‾). There were fewer responses to final stressed syllables than to final unstressed syllables because the initial syllable in iambic test items was more often deleted than the final syllable in trochaic test items. As mentioned earlier, monosyllabic responses to bisyllabic targets were discarded due to their ambiguous status as either monosyllabic or disyllabic words. Coda consonants were coded as “preserved” (66%), “deleted” (18%), “substituted” (13%), or “other” (3%). The classification “other” was used for productions of CVC.CVC words where deletion of one of the medial consonants had occurred and the remaining consonant was not identical to either the medial coda or medial onset of the target word, e.g., [bək.'mɪp] produced as [bə.'nɪp], and [gəp.'næk] produced as [gə.'mæk]. Coda consonants classified as “other” were not analysed further. Where the child omitted target nasal codas but produced some nasalization on the preceding vowel, these were coded as “deleted”. Mismatches in voicing between the target item and the participant’s response were ignored because a reliable voicing distinction in codas is late to develop (Stoel-Gammon & Buder, 1999).

Results

Analysis by age. The age range of the 15 participants in this study was quite large (1;7 to 2;6), raising the possibility that there might be variability in phonological development across this age range. However, there was no significant correlation between age and the proportion of total errors (substitutions and deletions combined) produced by each child ($r = .24$, $p > .10$). In fact, two of the children who produced the highest proportion of total errors were also among the oldest (aged 2;5 and 2;6). There was also no correlation between age and the proportion of errors broken down by error type (deletion errors, $r = .35$; substitution errors, $r = -.44$; both $p > .10$). Thus, in this particular group of children, age was not a good predictor of accuracy in producing coda consonants. However, we did find a negative correlation between age and the realization of bisyllabic targets as monosyllables ($r = -.71$, $p < .01$). Thus, younger children were more likely to delete the initial syllable in bisyllabic words that began with an unstressed syllable, e.g., [tə'bɛm] pronounced as [bɛm] (cf. Schwartz & Goffman, 1995). Because monosyllabic responses to bisyllabic words were discarded due to ambiguity regarding possible length effects, younger children tended to contribute fewer tokens to the final analysis. This did not skew the overall results as error rates for each child were calculated as a proportion of their total responses.

Deletion versus substitution errors. Deletions are one type of variability found in coda production. However, substitutions, where one consonant is replaced by another, also indicate that coda consonants have not yet been fully mastered (e.g., [gɒp'næk] → [gɒp'næp], [pʌgnəb] → [pʌgnəm]). A comparison of the pattern of results across the two types of errors – deletions and substitutions – was very similar. Using the Bonferonni procedure to control for Type 1 error, we compared the deletion and substitution errors across the 8 phonological contexts of interest.

We found that there were significantly fewer substitutions than deletions only for nasal codas in medial unstressed syllables [$t(14) = 4.94, p < .001$ (2-tailed)]. The very low rate of substitution for medial nasal codas (8%) was probably due to their very high deletion rate (79%); if a consonant is deleted it cannot also undergo substitution. There was no significant difference in the substitution and deletion rates for the other seven phonological contexts (final-stressed nasals, $t(14) = 1.42$; final-stressed stops, $t(14) = 1.63$; final-unstressed nasals, $t(14) = .57$; final-unstressed stops, $t(14) = 2.11$; medial-stressed nasals, $t(14) = 1.47$; medial-stressed stops, $t(14) = .97$; medial unstressed stops, $t(14) = 2.40$, all $p > .1$). Because the pattern of results for deletion and substitution errors were so similar, we combine these in the presentation of overall results below.

Overall results. To test for effects of phonological context on coda production, we looked at the production of stop and nasal codas with respect to stress environment (stressed vs. unstressed), position within the word (medial vs. final) and word length (monosyllabic vs. disyllabic). To evaluate the possible effects of stress environment, we compared the production of codas in stressed syllables (CV'CVC, CVC.'CVC, and 'CVC.CVC) with codas in unstressed syllables (CVC.'CVC, 'CVC.CVC, and 'CVCVC). To evaluate the possible effects of position within the word on coda production we compared performance on trochaic and iambic medial codas (CVC.CVC) with trochaic and iambic final codas (CVC.CVC and CVCVC). To determine whether word length had an effect on coda production, we compared the children's coda production accuracy in word-final codas in iambic test items (CV.'CVC and CVC.'CVC) with codas in monosyllabic test items ('CVC), thus ensuring that the codas being compared were all in stressed syllables occurring at the ends of words. Finally, to determine if there might be sonority

effects on coda production, we compared coda production accuracy on nasal and stop codas in both CVCVC and CVC.CVC words.

The mean proportions of total codas accurately produced as a function of context and sonority are given in Table 1. Proportions were normalized by arcsine transformation for the statistical analyses. A repeated measures ANOVA with position within the word (medial vs. final), stress environment (stressed vs. unstressed), and sonority (nasal vs. stop) as within-subject variables was applied to the proportions of the correct responses calculated for each condition. Significant main effects were found for both position in the word [$F(1,14) = 12.78, p < .05$] and stress [$F(1,14) = 29.53, p < .001$]. There was no main effect for sonority. Importantly, there was a significant interaction between position and stress [$F(1,14) = 14.16, p < .05$]. No other interactions were significant. As there was no main effect of sonority and no sonority interactions, planned contrasts (1-tailed) using the Bonferroni procedure to control for Type 1 error were conducted with nasal and stop codas combined (see Table 1). These contrasts show that there was an effect of stress in both medial and final position. In medial position, coda consonants were more accurately produced in stressed syllables than in unstressed syllables [$t(14) = 4.71, p < .001$]. In final position, codas were also more accurately produced in stressed syllables than in unstressed syllables [$t(14) = 2.89, p < .05$]. In unstressed syllables, there was an effect of position such that there were fewer errors in final position than in medial position [$t(14) = 3.13, p < .01$]. However, in stressed syllables, there were was no effect of position [$t(14) = 0.99, p > .1$].

Recall that codas in monosyllabic words are acoustically more salient than codas in longer words, as there is an inverse relationship between the number of syllables in a word and their duration, i.e., the same syllable is longer if it appears in a monosyllabic rather than a

bisyllabic word. We therefore wanted to determine if word-length had an effect on coda production accuracy, even when stress and position within the word were controlled. A repeated measures ANOVA with word length as the within-subject variable was applied to the total coda production accuracy calculated for each condition. There was a significant effect of word length on the accuracy of coda production as measured by production accuracy [$F(1, 14) = 5.83, p < .05$]. Thus, codas were more accurately produced in monosyllabic words (95%) than in iambs (82%).

To summarize, position within the word, stress environment, and word-length all affected the overall accuracy with which codas were produced. Coda consonants were more accurately produced in stressed syllables in both final and medial position. Furthermore, there was an effect of position within the word such that codas were more likely to be produced accurately in final position, but only in unstressed syllables. Word length also appears to influence the accuracy of coda production such that (final) codas in monosyllables were produced more accurately than final codas in bisyllables. However, we found no effect of sonority on coda production with both nasal and stop codas being produced with equivalent accuracy.

Discussion

These findings show that coda consonants are more accurately produced in acoustically prominent positions. It has long been known that stressed and word- or phrase-final syllables tend to have increased duration (e.g., Lieberman, 1960). Perhaps the increased duration of these syllables facilitates segmental encoding and retrieval. Furthermore, word-medial codas are always followed by additional segmental material, whereas word-final codas can be followed by silence when spoken alone or at the end of a sentence, further contributing to their perceptual salience. A perceptual account is also able to explain the greater difficulties in producing word-

final codas in bisyllables compared to codas in monosyllables, since codas in monosyllables are likely to be more acoustically salient due to their slightly longer duration as compared to codas in bisyllables. In addition, recall that word-initial unstressed CVC syllables, which have more phonetic content than word-initial unstressed CV syllables, were deleted less often in this study. Thus, one way to understand these results is in terms of enhanced perceptual encoding of acoustically prominent syllables, which results in more accurate lexical access, leading to better subsequent production.

There are, however, a few problems with this particular interpretation of the results. Although our study and others have shown more accurate production of segmental material in acoustically prominent syllables, researchers have also long known that children sometimes delete consonants from acoustically prominent syllables and replace them with consonants from acoustically weak word-initial unstressed syllables (e.g., *banana* → ['bænə] instead of ['nænə]) (cf. Fikkert, 1994; Demuth, 1995; Pater, 1997). This indicates that language learners must perceive the word-initial consonant, even though they delete the rest of the unstressed word-initial syllable. Thus, at least some of the distinctive features of consonants in unstressed syllables are encoded in children's lexical representations, even if they fail to produce them. We suggest the same is probably true for the coda consonants in this study. This raises questions about the validity of a perceptual/encoding explanation of children's early productions.

As an alternative to the perceptual explanation, there could be a production explanation for why acoustically prominent syllables tend to be preserved in children's early speech. Some researchers have proposed that constraints on the form of early words are caused by limited articulatory abilities rather than limited perceptual abilities (e.g., Hewlett, 1988; MacNeilage, 1980; Maxwell & Weismer, 1982; Scobbie, Gibbon, Hardcastle, & Fletcher, 2000). Thus,

children's early words differ from their adult targets because of poorly controlled articulators. Following this line of research, we suggest that the most important factor explaining the data presented here is that the longer duration of stressed syllables, final syllables, and monosyllables provides the articulators with more time to approximate their targets. We therefore argue that these results should be understood in terms of production rather than perception.

Perhaps there are equally good frequency explanations of the data. A growing body of research shows that young children are very sensitive to frequency effects in the language to which they are exposed. Young children's sensitivity to phonological frequency has been shown in studies of both perception (Anderson, Morgan, & White, 2003; Jusczyk, 1997; Morgan, 1996; Saffran, Aslin, & Newport, 1996) and production (Beckman & Edwards, 2000; Edwards, Beckman & Munson, 2004; Levelt, Schiller, & Levelt, 2000; Roark & Demuth, 2000; Zamuner, 2003; Zamuner, Gerken & Hammond, 2004). For example, language-learners appear to produce higher frequency phonotactic (CV) structures earlier than lower frequency structures. Levelt, et al. (2000) show that Dutch-learning children's progression from simple CV syllable structure to more complex CCVCC syllable structure corresponds closely to the frequency with which these different syllable structures occur in child-directed speech. Furthermore, Stites, Demuth & Kirk (2004) show that English-speaking children's first coda consonants include higher-frequency stops, with lower frequency nasals and fricatives acquired later (see Kehoe & Stoel-Gammon (2001) for similar findings). In addition, Zamuner et al., (2004) find that children are sensitive to the transitional probabilities between the vowel and the following coda consonant in word-production tasks. These results suggest that learners are able to keep track of frequency effects at several different levels of syllable structure. Perhaps language learners initially produce coda

consonants in the phonological contexts where codas most frequently occur, only later producing them in lower frequency contexts.

In the following section, we examine the frequency of coda consonants as a function of phonological context and sonority. It is possible that codas will be more accurately produced in high-frequency contexts, and less accurately produced in low-frequency contexts. This will allow us to determine whether frequency can also account for 2-year-olds' variable production of coda consonants.

Study 2: Coda Consonant Frequency Across Different Contexts

Method

In this study we consider the possibility that coda consonants will be more accurately produced in contexts where they frequently appear in English, and will be less accurately produced in contexts where coda consonants in English are rare. To test this hypothesis we must first determine the frequency of English coda consonants in different contexts. To do this, we calculated the frequency of single codas as a function of stress (stressed vs. unstressed syllables), position within the word (word-medial vs. word-final), word-length (monosyllabic vs. bisyllabic words) as well as by sonority (stops vs. nasals). To determine the frequency of codas in these different contexts, we examined a large sample of child-directed speech. This sample consisted of the utterances of parents and experimenters to 3 children learning American English, providing a representative sample of the speech that children are typically exposed to (e.g., dinner table talks, activities of free plays, and storytelling). The data for all 3 children were collected by Brown (1973) and include adult speech heard by Adam (2;3-4;10), Eve (1;6-2;3), and Sarah (2;3-3;5). These files are available from <http://chilides.psy.cmu.edu> (MacWhinney, 2000). All open class words were extracted, syllabified and phonemicized using the online

English version of the CELEX database (Center for Lexical Information)

(<http://www.ru.nl/celex/>). To match the test items used in our experimental study as closely as possible, we extracted only monosyllabic words with single codas and bisyllabic words with single word-medial and word-final codas. A total of 147,614 syllables with codas were analysed with 121,084 codas from monosyllabic words and 26,530 codas from bisyllabic words.

Results

The results showed that codas in monosyllables were overwhelmingly more frequent than in bisyllables by virtue of the very high frequency of monosyllabic words in English, many of which are CVC. There were 121,084 monosyllables with single codas, but in bisyllabic words with a final stressed syllable there were only 3,282 single codas. On frequency grounds alone we would expect better coda production in monosyllables than in bisyllables with word-final stress. In the remainder of this section, we focus on the distribution of coda consonants in bisyllabic words.

First, we wanted to know whether the accuracy of coda production was influenced by the frequency of the context in which a coda consonant occurred (medial-stressed, medial-unstressed, final-stressed, final-unstressed). These frequency counts are presented in Table 2. For these calculations, we took all codas in bisyllables in our sample and separated them by sonority type (stops, nasals, fricatives, liquids). Then for each sonority type, we calculated the proportion of codas in each of the four contexts, e.g., we calculated the proportion of stop codas that were in word-final unstressed syllables. We found that for all sonority types, codas were most likely to occur in word-final unstressed syllables. Thus, on frequency grounds, we would expect codas to be most accurately produced in word-final unstressed syllables. Note that although we present

the frequency counts for all sonority types, our experimental study included only stop and nasal codas.

Second, we wanted to compare the frequency of stops and nasals in different contexts. These proportions are shown in Table 3. Here we calculated the proportion of nasals vs. stops in each of the four contexts. We found that in final stressed syllables, there were many more stop codas than nasal codas, while in medial stressed syllables, the reverse held. Thus, if frequency determines production accuracy, we would expect nasal codas to be most accurately produced in medial stressed syllables, and stop codas to be most accurately produced in final stressed syllables.

Discussion

If frequency plays a role in coda production accuracy, we would expect better accuracy on unstressed rather than stressed syllables in word-final position (see Table 2). However, this is not what we find. The results reported in Table 1 show that the children in this study were significantly more accurate at producing codas in word-final stressed rather than word-final unstressed syllables. Frequency also predicts that in word-medial stressed syllables, nasals will be more accurately produced than stops, while in word-final stressed syllables, stops will be more accurately produced than nasals (see Table 3). However, as discussed in the results section of Study 1, there were no significant effects by sonority. Both stops and nasals were more accurately produced in acoustically prominent positions. Thus, it appears that frequency, at least in the way we have defined it here, fails to explain the results of our coda production study.

Perhaps, however, performance on individual segments provides evidence for frequency effects. Table 4 presents the proportion of individual coda segments in child-directed speech as a function of position within the word, drawn from the corpora we investigated in Study 2. These

are collapsed across stress conditions due to their relatively low overall frequency. In word-final position, [k] was the most frequent coda, with the nasals [m] and especially [n] being the most frequent word-medially. However, coda production accuracy on word-medial [n] is extremely poor. In contrast, performance on low frequency word-final [g] is extremely good. Thus, it appears that the frequency of individual coda consonants as a function of position within the word is not a good predictor of accuracy in coda consonant production, at least for the children in this study. It is possible that if high-frequency [t] had been included in our study, we would have found a frequency effect, since it is one of the earliest coda consonants produced (e.g., Kehoe & Stoel Gammon, 2001; Stites, et al, 2004). This is obviously an area for further research.

One factor that might affect counts of coda frequency is the possibility that some codas that are orthographically transcribed for child-directed speech are severely reduced in actual speech. For example, the final consonant in the word *hand* is often produced as [hæn]. Labov (1970) has shown that speakers of English may variably reduce consonants at the ends of words. It is not clear if adults reduce speech to the same extent in talking with two-year-olds, and if so, how this reduced coda consonant input might affect either our coda frequency counts or children's production of coda consonants across contexts. Further research is needed to more closely examine the phonetic content and acoustic variability in child-directed speech to determine the possible effect this might have on children's early word productions.

In sum, the coda production results in Study 1 cannot be easily explained by frequency effects. How, then, do we account for the previously reported effects of frequency where higher-frequency syllable structures are acquired before lower frequency syllable structures in both Dutch and English (Levelt, et al., 2000, Stites, et al., 2004). We suggest that this may be due to methodological issues. Both these studies were conducted using spontaneously produced known

words, and both only considered productions in word-final stressed syllables. Therefore, acoustic prominence was not investigated as a possible factor in syllable structure development in these studies. This suggests that frequency effects, at least with respect to the acquisition of syllable structure and segmental structure, may play a role in the course of language development, but only when factors, such as stress and position within the word, are held constant.

General Discussion

In this paper, we examined the production of coda consonants by two-year-olds in different phonological contexts using a controlled set of novel words in an elicited production task. The results showed that the production of single codas by young children learning English is affected by stress environment, position within the word, and word length. However, there was little evidence of sonority affecting production accuracy of codas. Like Zamuner and Gerken's (1998) novel word production task, we found that children are more likely to produce codas target-appropriately in stressed syllables. However, we extended Zamuner and Gerken's results with our finding that the effect of stress also holds in word-medial position. Independent of stress, we also found an effect of position within the word such that codas in word-final position are more likely to be produced accurately than codas in word-medial position. However, the effect of position within the word held only for unstressed syllables, with no difference in production accuracy in stressed syllables between codas in medial and final position. In addition, word-final codas are more problematic in bisyllabic words than in monosyllabic words, even when stress was controlled.

This pattern of results is consistent with an account where acoustically prominent positions convey a positive effect on the production of coda consonants. Because existing data cast doubt on purely perceptual accounts of the role of acoustic prominence, we argue that

acoustically prominent syllables, which have longer durations in a language like English, provide learners with more time to articulate coda consonants, thereby enhancing production accuracy.

We have also showed that a frequency account of the data fails to explain these results.

There remains the problem of explaining the discrepancy between our findings and those of Zamuner and Gerken (1998) concerning the effect of sonority on coda production. Recall that in unstressed syllables, Zamuner and Gerken found that word-final stops were more likely to be deleted than word-final liquids and nasals, whereas we found no effect of sonority on coda production. The mean age of the participants in both Zamuner and Gerken's study and in ours was 2;2 years, therefore, differences in chronological age cannot explain these disparate results. However, there were several differences between the two studies that may have contributed to the different findings. Different test items were used, these test items were presented by different experimenters, and subject recruitment procedures may have been different. It is possible that our participants may have been more phonologically advanced than their peers. When we compare the production of codas in monosyllables across both studies, we notice that the rates of coda deletion were very different. In our study, deletion of codas occurred in less than 2% of monosyllabic test items, while in Zamuner and Gerken's study, codas were deleted in 33% of monosyllables. Deletion rates in Zamuner and Gerken ranged from 50% for coda /m/ to 20% for coda /ŋ/. The much higher rate of coda deletion in monosyllables by the children in Zamuner and Gerken's study suggests that although the participants in both studies were the same age chronologically, they were at different stages in the acquisition of singleton codas. Perhaps sonority affects the production of codas only at the earliest stages of coda acquisition, and the children in our study had already progressed through this stage.

Could representational or structural issues account for the results found in our study? As discussed previously, it has been proposed that word-final consonants in languages like French are actually onsets to empty-headed syllables (CV.C \emptyset), and that true codas only occur word-internally. This is used to explain the fact that word-final consonants are acquired earlier than word-medial codas in French (Rose, 2000). Thus, our finding that children produced more errors with word-medial codas than in word-final codas could be taken as support for the view that children's word-final consonants are not codas at all, but are the onsets to empty-headed syllables (Goad & Brannen, 2003; Harris, 1994; Piggott, 1999). On this account, children acquire the two different types of onset (a consonant preceding a nucleus with phonetic content, e.g., $\underline{C}V$, and a consonant preceding an empty nucleus, e.g., CV. $\underline{C}\emptyset$), before acquiring true codas (a consonant that is separated from the following consonant by a phonotactic boundary, e.g., CVC. $\underline{C}V$). However, a structural account is less successful at explaining the effect of stress environment on coda production. For such an account to go through, we would have to assign a different structure to a consonant at the right edge of a stressed syllable than to a consonant at the right edge of an unstressed syllable. It is difficult to justify such a move if its only purpose is to explain differences in ease of production and order of acquisition.

Finally, the reader may have been wondering about possible processing factors that might have influenced the findings reported here. For example, both the word-length effect and the poorer performance on word-medial than word-final codas could easily be understood in terms of processing factors. Many psychological theories of processing would predict that middles of words would be harder to remember (and produce) than information at the beginning or ends of words (for example, see Slobin's (1985) *Operating Principles for learning language*). Furthermore, psychological experimentation has repeatedly shown that children are sensitive to

the number of syllables or words in a sentence, and that as the processing load increases, performance decreases (e.g., Gathercole & Baddeley, 1993). Thus, perhaps the data reported in our study can be understood in terms of general processing constraints. However, there are two reasons to argue against a simple processing account of the findings reported here. First, a processing account cannot explain the much poorer performance on medial unstressed codas compared with medial stressed codas in bisyllabic words. Furthermore, results from longitudinal spontaneous production studies of coda acquisition in Spanish shows that word-medial codas are acquired before word-final codas (Lleó, 2003), suggesting that there is nothing inherently difficult about producing codas in the middle of a word. Lleó explains these results as a function of stress, where word-final codas in Spanish typically occur in unstressed syllables. Not having yet explored the frequency distribution of coda consonants in Spanish, we know little about the predictions that frequency would make. However, these data may provide some crosslinguistic support for the proposal that coda consonants are more accurately produced in acoustically prominent syllables, with the longer duration of these syllables providing learners more time to complete their articulatory targets.

We might then predict that other contexts containing increased duration would also show increased preservation of coda consonants. In fact, Hsieh, Leonard, & Swanson (1999) argue that durational effects may help explain the differential production of word-final English *-s* morphemes: plural *-s* is easier to produce (and earlier acquired) than third person singular *-s* because nouns tend to occur phrase finally, where word-final syllable duration is enhanced, whereas verbs tend to occur phrase medially, where word-final syllables are shorter in duration.

One of the longstanding theoretical issues in the study of language development has been how to interpret variability in children's early productions. The variable production of segments

has generated much debate, with implications for what constitutes normal phonological development versus language delay. In this paper we have shown that at least some of the variability found in normally developing two-year-olds' production of single coda consonants is systematic. Furthermore, an accurate characterization of coda acquisition must consider the phonological context in which these segments occur.

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Appendix

Materials by word shape and coda consonant.

codas	'CV <u>C</u>	CV' <u>CV</u> C	'CVC <u>V</u> C	'CV <u>C</u> . CV <u>C</u>	CV <u>C</u> . 'CV <u>C</u>
p	'gɛp	nə'gɛp	'nɛgɔp	'gɛpnək	gəp'næk
b	'kɛb	mə'kɛb	'mɛkəb	'kɛbmæg	kəb'mæg
k	'bɪk	mə'bɪk	'mɪbək	'bɪkməp	bək'mɪp
g	'pʌg	nə'pʌg	'nʌpɛg	'pʌgnəb	pɛg'nʌb
m	'bɛm	tə'bɛm	'tɛbəm	'bɛmnək	bəm'nɪk
n	'gɛn	də'gɛn	'dɛgən	'gɛnməl	gən'mɛl
l	'mʌl	tə'mʌl	'tʌməl	'tʌlmən	təl'mʌn

Author Note

Cecilia Kirk, Department of Communication Disorders, University of Canterbury, New Zealand, and Katherine Demuth, Department of Cognitive and Linguistic Sciences, Brown University.

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Correspondence concerning this article should be addressed to Cecilia Kirk, Department of Communication Disorders, University of Canterbury, New Zealand. Email:

cecilia.kirk@canterbury.ac.nz.

Table 1.

Mean proportions (and standard deviation) of target coda consonants correctly produced as a function of context and sonority

	Stops		Nasals		Total	
Monosyllables	0.91 (0.13)		0.96 (0.13)		0.93 (0.11)	
	Stops		Nasals		Total	
Bisyllables	Medial	Final	Medial	Final	Medial	Final
Stressed	0.75(0.28)	0.78(0.23)	0.76(0.32)	0.80(0.29)	0.76(0.20)	0.79(0.17)
Unstressed	0.29(0.33)	0.64(0.28)	0.12(0.42)	0.75(0.29)	0.23(0.29)	0.67(0.24)

Table 2.

For each sonority type, the proportion of codas as a function of context (in bisyllabic words)

	Stops		Nasals		Fricatives		Liquids	
	Medial	Final	Medial	Final	Medial	Final	Medial	Final
Stressed	0.12	0.33	0.28	0.05	0.14	0.20	0.05	0.03
Unstressed	0.01	0.54	0.02	0.66	0.0	0.66	0.11	0.82

Table 3.

For each context, the proportion of codas as a function of sonority (in bisyllabic words)

	Stops		Nasals		Fricatives		Liquids	
	Medial	Final	Medial	Final	Medial	Final	Medial	Final
Stressed	0.16	0.60	0.62	0.14	0.11	0.21	0.10	0.06
Unstressed	0.05	0.18	0.16	0.35	0.0	0.11	0.79	0.36

Table 4.

Proportion of codas in child-directed speech compared with proportion correctly produced (and standard deviation) as a function of segment type and position within the word

	Segmental Frequency		Correctly Produced (SD)	
	Medial	Final	Medial	Final
p	0.02	0.0	0.43 (0.38)	0.67 (0.33)
b	0.01	0.0	0.28 (0.36)	0.64 (0.33)
k	0.08	0.1	0.83 (0.31)	0.72 (0.36)
g	0.0	0.0	0.62 (0.35)	0.73 (0.30)
m	0.1	0.05	0.5 (0.41)	0.62 (0.44)
n	0.31	0.07	0.44 (0.33)	0.85 (0.23)