J. Child Lang. **32** (2005), 709–734.
doi:10.1017/S0305000905007130 Printed in the United Kingdom

Asymmetries in the acquisition of word-initial and word-final consonant clusters*

CECILIA KIRK AND KATHERINE DEMUTH

University of Canterbury and Brown University

(*Received* 4 *May* 2004. *Revised* 8 *April* 2005)

ABSTRACT

Previous work on the acquisition of consonant clusters points to a tendency for word-final clusters to be acquired before word-initial clusters (Templin, 1957; Lleó & Prinz, 1996; Levelt, Schiller & Levelt, 2000). This paper evaluates possible structural, morphological, frequency-based, and articulatory explanations for this asymmetry using a picture identification task with 12 English-speaking two-year-olds. The results show that word-final stop+/s/ clusters and nasal+/z/ clusters were produced much more accurately than word-initial /s/+stop clusters and /s/+nasal clusters. Neither structural nor frequency factors are able to account for these findings. Further analysis of longitudinal spontaneous production data from 2 children aged 1;1–2;6 provides little support for the role of morphology in explaining these results. We argue that an articulatory account best explains the asymmetries in the production of word-initial and word-final clusters.

INTRODUCTION

Previous research on the acquisition of consonant clusters in English has focused primarily on word-initial clusters (e.g. Templin, 1957; Chin & Dinnsen, 1992; Smit, 1993; Gierut, 1999; Barlow, 2001; McLeod, van Doorn & Reed, 2001; Pater & Barlow, 2003; Gnanadesikan, 2004; Goad &

[*] Research and manuscript preparation were supported by National Institute of Mental Health Grant #1R0 IMH60922-01A2 awarded to the second author. Many thanks to Manuela Barcelos, Jessica Goldberg, and Patrick Tonks for help with running the experiment and transcribing the data. Thanks to Jessica Stites for help with data analysis. We are very grateful to Jae Yung Song for generously sharing her longitudinal data on word-final cluster acquisition. Thanks also to Matt Goldrick, Michelle Gregory, Dave Sobel, and two anonymous reviewers for helpful comments. Finally, we would like to thank the parents and children who participated in the research. Address for correspondence: Department of Communication Disorders, University of Canterbury, Private Bag 4800, Christchurch 8020, New Zealand. e-mail: cecilia.kirk@canterbury.ac.nz

Rose, 2004).[1] Much of this literature has been concerned with whether children's consonant cluster reduction patterns are best explained by sonority (e.g. Ohala, 1999; Pater & Barlow, 2003; Gnanadesikan, 2004), headedness (Goad & Rose, 2004), or directionality, (i.e. whether C1 or C2 is more likely to be preserved (Lleó & Prinz, 1996)). The order in which different word-initial clusters are acquired has also received much attention. Many of these studies focus on children's cluster production without reference to the standard adult pronunciation (e.g. Stoel-Gammon, 1987; Watson & Scukanec, 1997). There are also a number of studies that compare children's attempts at consonant clusters in relation to the standard adult form (Templin, 1957; Smit, 1993).

However, there has been relatively little discussion of how and when clusters in word-final position are acquired, especially regarding children's productions relative to the standard adult pronunciation. Templin (1957) found that English-speaking children aged 3;0, and 3;6 produced word-final clusters more accurately than word-initial clusters. McLeod *et al.* (2001) followed 16 English-speaking two-year-olds over a six-month period. They found that both word-initial and word-final clusters were correctly produced in the inventories of the youngest participants. However, no percentages are given for correct cluster production in initial vs. final position, so there is no way of comparing cluster accuracy as a proportion of the total number of attempted clusters in these two positions. Furthermore, not many stimuli were provided to elicit word-final clusters, and morphologically complex clusters were eliminated from the sample. Both these factors are likely to underestimate the number of final clusters produced correctly.

Some research has been conducted on the acquisition of word-final clusters in languages other than English. Lleó & Prinz (1996) examined longitudinal data from five German-speaking children between the ages 0;9–2;1. These children acquired word-final clusters several months before word-initial clusters, and word-final clusters were more accurately produced than word-initial clusters, although this difference was not significant. Levelt *et al.* (2000) examined syllable structure development in longitudinal data from 12 children learning Dutch (1;0–1;11 years at the outset of their study). They found that 9 of the children acquired CVCC syllable structures before CCVC structures, while the remaining three children showed the reverse order of acquisition.

These previous studies point to a tendency for word-final clusters to be acquired before word-initial clusters, at least in these Germanic languages.

[1] The term consonant cluster will be used throughout as a cover term to refer to two types of consonant sequences: those that form true clusters, and those that consist of a singleton consonant plus an appendix.

This finding is surprising given that word-final singleton consonants tend to be acquired later than word-initial singletons. This might lead us to expect that complex syllable structure will develop in word-initial position before it does in word-final position. On the other hand, if we look at the occurrence of consonant clusters crosslinguistically we see that there are languages that permit only word-initial clusters (e.g. Spanish) as well as languages that permit only word-final clusters (e.g. Finnish). Thus, cross-linguistically, word-final clusters are no more marked than word-initial clusters, leading us to expect that clusters at the beginnings and ends of words will be acquired at the same time.

Neither the German nor the Dutch study provides a breakdown of cluster accuracy according to the segments that make up those clusters. Yet it is well established, at least for word-initial clusters, that some consonantal sequences are acquired before others (Templin, 1957; Smit, 1993). Thus, a child may produce word-initial /s/+stop clusters correctly before word-initial /s/+nasal clusters. In order to provide an explanation for the earlier acquisition of word-final clusters, it is essential to compare performance on clusters that are matched for segmental material.

The purpose of the current study is to evaluate several possible explanations for the reported asymmetry in the acquisition of consonant clusters in initial and final position. To do this, we consider English-speaking two-year-olds' acquisition of consonant clusters using data from both experimental and longitudinal studies. We then evaluate possible structural, morphological, frequency-based, and articulatory explanations for this asymmetry. Each of these possible explanations is considered below.

One possible explanation for the more accurate production of word-final clusters is that these clusters have simpler structure than word-initial clusters, and these simpler structures are easier to acquire and/or produce. However, for this explanation to go through, we need to justify assigning simpler structure to word-final clusters. In some theories of syllabification, syllables have no internal structure apart from the segments themselves (e.g. Kahn, 1976; Clements & Keyser, 1983), but most theories of the syllable assume that a syllable contains subparts. The nucleus is the syllable's essential core and the only obligatory part of the syllable. It can be preceded by an optional onset consonant and followed by an optional coda consonant. The nucleus and the coda are often grouped together to form a subconstituent called the rhyme (or rime). The constituents of the syllable are illustrated with the word *pig* in Figure 1a.

In word-initial position, a sequence of two consonants is generally analysed as a branching onset, as depicted in Figure 1b with the word *drum*. We ignore for the moment, the special status of word-initial clusters with /s/ as the first element. However, in word-final position, some researchers have argued that consonant clusters are non-branching (e.g. Selkirk, 1982). First,

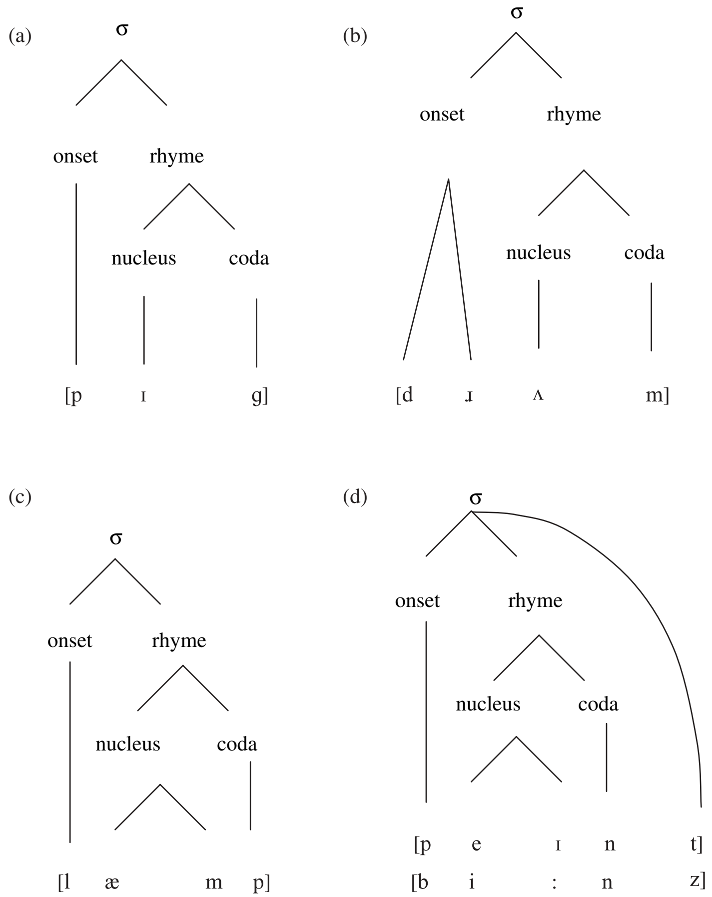

Fig. 1. Representations of syllable structure. (a) Constituents of the syllable. (b) Subsyllabic structure of a word-initial branching onset (stop+liquid). (c) Subsyllabic structure of a word-final sonorant+consonant cluster when the vowel is lax (d) Subsyllabic structure of a word-final sonorant+consonant cluster when the vowel is a diphthong or tense.

we justify non-branching structure for word-final sonorant+consonant clusters. In English, diphthongs and tense vowels cannot occur before final sonorant+consonant clusters, unless the rightmost member of the cluster is coronal. For this reason, it has been argued that these clusters should be prosodified with the sonorant as part of the nucleus when the vowel is lax, (e.g. *lamp*) (see Figure 1c). When the vowel is tense, however, the sonorant is prosodified as the coda, and the final coronal consonant is housed in an appendix that is adjoined to the preceding syllable (e.g. *paint*, *beans*) (see Figure 1d). Thus, the sonorant consonant in these clusters is prosodified as

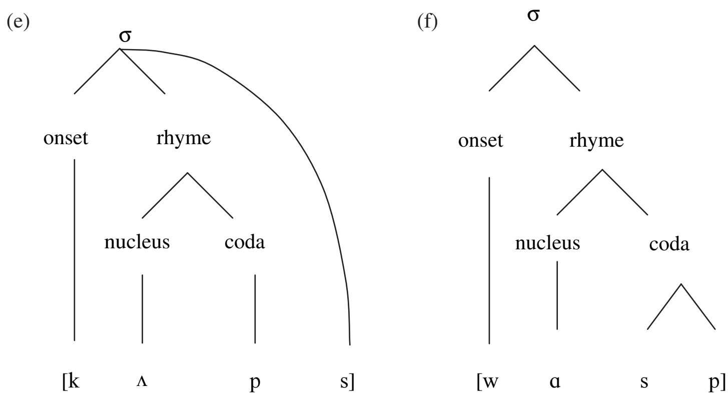

Fig. 1 (Cont.). Representations of syllable structure. (e) Subsyllabic structure of a word-final coda plus appendix (stop + /s/). (f) Subsyllabic structure of a word-final branching coda (/s/ + stop).

part of the nucleus if a prosodic position (i.e. a mora) is available, but as a singleton coda, if not. In both cases, under this analysis, word-final sonorant + consonant clusters are non-branching, and might therefore be easy to acquire.

Having justified non-branching structure for word-final sonorant + consonant clusters, this leaves us with determining the structure of word-final stop + fricative clusters (e.g. *cups*), final stop + stop clusters (e.g. *stopped*), final fricative + fricative clusters (e.g. *gloves*), and final fricative + stop clusters (e.g. *nest*). With the exception of word-final /sp/ and /sk/, the second consonant in all these clusters is a coronal obstruent, and the special status of these coronal clusters has been acknowledged by housing the coronal in an appendix (e.g. Halle & Vergnaud, 1980) (see Figure 1e). Word-final clusters consisting of /s/ + stop (e.g. *wasp*) have sometimes been analysed as complex singletons (much like affricates) rather than consonant clusters (Selkirk, 1982). However, this analysis appears to be motivated solely by the requirement that word-final clusters be non-branching. An alternative would be to analyse /s/ + stop clusters as the only true clusters in word-final position, with both consonants housed in a branching coda (Figure 1f).

If we adopt the analysis that word-final clusters (except for /s/ + stop clusters) are non-branching, and so are less complex than word-initial clusters like that in *drum* (see Figure 1b), then we can explain why word-final clusters might be easier to acquire than word-initial clusters. However, not all word-initial clusters are analysed as having branching structure. Word-initial /s/ + stop clusters violate a principle called the SONORITY CYCLE (Clements, 1990) according to which the sonority of the preferred syllable

(g)

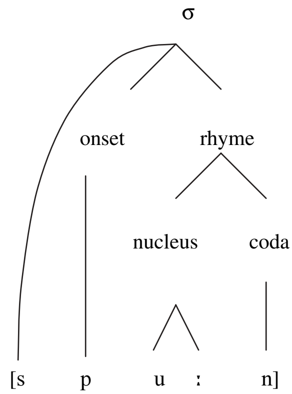

Fig. 1 (Cont.). Representations of syllable structure. (g) Subsyllabic structure of a word-initial appendix plus onset (/s/+stop).

type should rise maximally from onset to nucleus, and fall minimally within the rhyme. For this reason word-initial /s/+stop clusters, as in *spoon*, are commonly analysed as consisting of an appendix followed by a singleton onset (e.g. Giegerich, 1992) (see Figure 1g). One way of testing a structural explanation for the order of cluster acquisition is to compare clusters that are structurally and segmentally equivalent, such as word-initial /s/+stop and word-final stop+/s/ clusters (Figures 1g vs. 1e). The structural hypothesis predicts that the asymmetry in the production of initial and final clusters should disappear for these clusters because they have identical structure. Comparing production accuracy on these clusters will determine whether the superior performance in the production of final clusters can be explained by structural differences between clusters in initial and final position.

An alternative explanation for the positional asymmetry in the acquisition of clusters is morphological. In English, many word-final clusters contain important morphological information (e.g. *ducks*), whereas there is no morphological content in word-initial clusters. Perhaps the presence of these word-final morphemes serves to focus children's attention on the ends of words (*cf*. Slobin, 1973), thereby leading to more accurate production of word-final clusters. This would predict better performance on *ducks* /dʌks/ than on *school* /skul/. Furthermore, it might also predict better performance on bimorphemic than on monomorphemic word-final clusters, with more accurate and earlier production of *ducks* /dʌks/ than *box* /bɑks/.

On the other hand, perhaps frequency plays a role in the earlier acquisition of word-final clusters. Recent research in both infant speech perception and early language production indicates that language learners are sensitive to the frequency with which different phonological structures occur in the language(s) they are learning, including lower-level structures such as segments, phoneme sequences and stress placement (see Munson, 2001 for a recent review of this literature), as well as higher-level phonological units such as syllable and prosodic word structures (Levelt *et al.*, 2000; Demuth, 2001).

Zamuner, Gerken and Hammond (2004) used a nonword repetition task to investigate the role of the transitional probabilities of adjacent segments in the speech of English-speaking two-year-olds. The children in this study produced codas more accurately in non-words with high transitional probablilities, e.g. [sɪg], than in non-words with low transitional probablilities, e.g. [θæg], thus showing sensitivity to the frequency with which segments co-occur. Levelt *et al.* (2000) have shown a relationship between the order of acquisition of different syllable types in Dutch and their frequency in child-directed speech. The children in their study acquired more frequent syllable types earlier than less frequent ones.

It has also been shown that frequency may influence production accuracy at the level of the word, with high frequency words being produced more accurately than low frequency words (Berry & Eisenson, 1956; Leonard & Ritterman, 1971). On the other hand, other studies (Moore, Burke & Adams, 1976; Bennett & Ingle, 1984) suggest that word frequency has little effect on production accuracy. However, the participants in these studies were seven-year-olds enrolled in articulation therapy for correction of /s/, so it is not clear how well these findings generalize to younger, typically developing children.

As discussed above, children are sensitive to the frequency of phonological patterns at many levels of linguistic representation. It could be that English-speaking children produce word-final clusters more accurately than word-initial clusters because word-final clusters occur more frequently in the ambient language and children are sensitive to this difference in frequency. One factor affecting the production accuracy of clusters in word-initial and word-final position might be segmental frequency and/or phonotactic (CV) frequency. Another factor influencing cluster production might be word frequency. However, in our study, we decided not to manipulate word frequency. We wanted to collect spontaneous productions of pictureable words familiar to two-year-olds, so it was not possible to elicit words that varied widely in frequency. It is worth noting that the participants in studies that have manipulated word frequency were several years older than our participants, and these studies elicited imitated rather than spontaneous productions.

There are two potential explanations for better production accuracy on high frequency phonological structures. Frequently occurring structures are heard more often by the child and so offer more opportunities for discrimination. High frequency structures also offer more opportunities for practicing correct production. Much of the time, these two types of frequency will overlap. Thus, the frequency with which a structure is heard by a child and the frequency with which a structure is produced by a child will be similar. However, it is also possible that the frequency with which children attempt particular structures or words may be different from the frequency with which children hear these structures and words. In this study, we did not attempt to test the hypothesis that the words children produce more frequently are also those that are produced more accurately. Given the experimental nature of the task, the frequency with which the children in our study produced the test items was very similar across items.

Another possible explanation for the reported asymmetry in the acquisition of word-initial and word-final consonant clusters is that some sequences of consonants are easier to produce than others because of their phonetic context (e.g. Kent, 1982). For example, Gallagher & Shriner (1975*a*, 1975*b*) report more accurate production for word-initial /s/ followed by /t/ or /d/ than for /s/ followed by vowels. Furthermore, House (1981), in a reinterpretation of data originally presented by Mazza, Schuckers & Daniloff (1979), shows that /s/ is more accurately produced in word-final stop + /s/ clusters than in word-initial /s/ + stop clusters (where it was preceded by a word ending in a voiceless stop). Again, the articulatory demands are different in the two contexts; the initial /s/ is preceded by the stop gap of a voiceless consonant whereas the final /s/ is realized as the release of a stop consonant.

An alternative articulatory account of the cluster asymmetry is that certain sequences of consonants are more difficult to articulate than other sequences, regardless of phonetic context. Thus, we might expect similar accuracy on /s/ + stop clusters in both word-initial and word-final position. For example, production of the initial /st/ cluster in *star* should be just as accurate as the final /st/ cluster in *toast*.

The purpose of the present study is, therefore, to evaluate the possible contributions of these structural, morphological, frequency, and articulatory factors for explaining the earlier acquisition of word-final consonant clusters. It is hoped that this will lead to a better understanding of the processes underlying the acquisition of phonological structure more generally.

STUDY 1

METHOD

Participants

The participants in Study 1 were 12 two-year olds (7 girls, 5 boys) from monolingual English-speaking homes in Rhode Island. Their mean age was 2;1 (range: 1;5–2;7).

Materials

The test items were picturable, monosyllabic English nouns and colour adjectives with a CC cluster in either word-initial position or word-final position. A complete list of the test items is provided in Appendix A. Occasionally, children spontaneously produced words, including verbs, with word-initial or word-final clusters that were not specifically elicited by the experimenter. These items were included in the analysis and are listed in Appendix A where they are marked by an asterisk. Words with CC clusters in both word-initial and word-final position were not analysed, except for productions of /mz/ in the word *drums*. This CCVCC word was included in the analysis because there are few nouns familiar to two-year-olds that end in the cluster nasal+/z/ that can also be easily represented in picture form. Most productions by the participants in the study were single words. However, if multi-word utterances were produced, only word-initial clusters that were also utterance-initial, and word-final clusters that were also utterance-final were analysed. This was to eliminate instances where the syllabification of clusters across word boundaries was unclear.

The following cluster types were targeted: word-initial /s/+stop, word-initial /s/+nasal, word-initial stop+/l/, word-initial stop+/ɹ/, word-final nasal+/z/, word-final stop+/s/, word-final nasal+stop, word-final /s/+stop. Word-final clusters involving liquids were not targeted. The dialect of English spoken by local Rhode Islanders has no /ɹ/ in post-vocalic position. Furthermore, two-year olds also have difficulty producing word-final liquid+consonant clusters accurately; they typically glide post-vocalic liquids, both when the liquid is a singleton and when it is the first element of a word-final cluster (Ohala, 1999). Thus, production difficulties with word-final liquid+consonant clusters are not specific to clusters. For this reason, we did not attempt to elicit words with word-final liquid+consonant clusters. Word-final clusters consisting of two stops and word-final clusters consisting of two fricatives were not targeted since, with the exception of *gloves*, nouns containing these clusters are unfamiliar to two-year olds.

Procedure

Pictures and toys were used to elicit the test items. The experimenter showed the child a picture or toy and asked 'What's this?'. Spontaneous productions were elicited where possible, otherwise imitations were encouraged. Each child was digitally recorded with a SONY ECM-MS907 stereo condenser microphone held within 16 inches of the child's mouth. All children were recorded in two play sessions on consecutive days. Recording each child in two separate sessions enabled us to collect multiple productions of a large number of target clusters differing in sonority type.

TABLE 1. *Examples of productions classified as errors*

Error type	Target word	Child's response
Reduction	glove /glʌv/	[ˈgʌv]
Substitution	swing /swɪŋ/	[ˈfwɪŋ]
Coalescence	spoon /spun/	[ˈfun]
Metathesis	toast /toʊst/	[ˈtoʊts]
Non-schwa epenthesis	blue /blu/	[ˈbʌlu]
Deletion	desk /dɛsk/	[ˈdɛ]

This allowed us to calculate the number of clusters that were correctly produced relative to the total number of attempted clusters. Each session lasted between 20 and 40 minutes and took place either in the child's home or in a quiet room at their childcare centre.

Data transcription and analysis

All data were transcribed off-line by two independent transcribers using broad phonetic transcription. Any differences between the two transcribers were resolved by consensus. If consensus could not be achieved, a third transcriber was consulted and the issue was resolved, or the item was discarded (less than 0·5% of the total items). One of the transcribers was the first author and all transcribers were experienced in transcribing the speech of young children.

When a child's response matched the standard adult pronunciation, it was classified as being produced correctly, otherwise, it was classified as an error. Table 1 gives examples of the types of productions that were classified as errors. However, there were some mismatches between the adult form and the child's response that were ignored. Mismatches in voicing between the target cluster and child's production were not coded as errors since a reliable voicing distinction in codas is late to develop (Stoel-Gammon & Buder, 1999). For example, if *pigs* /pɪgz/ was pronounced as [pɪks], the child was considered to have produced this cluster correctly. Following Smit *et al.* (1990), clusters where schwa was inserted between the first and second element were not coded as errors. Schwa epenthesis only occurred in word-initial consonant+sonorant clusters, possibly representing a lengthened transition into the sonorant rather than true vowel insertion. Note, however, that productions where a full vowel was epenthesized were coded as errors.

If consonants were mispronounced as singletons, then this same pronunciation in clusters was not penalized. For example, if a child realized singleton /s/ in word-initial position as [ʃ], then [ʃpun] was considered to be an acceptable pronunciation for *spoon* /spun/. Similarly, if a child pronounced singleton /l/ and /ɹ/ as [w] then [dwʌm] was considered an

TABLE 2. *Production accuracy by cluster type*

Cluster type	% correct (S.D.)	# children ≥75% accuracy	# children 50–74% accuracy	Weighted accuracy
Word-final nasal+/z/	85 (30)	9	2	20
Word-final stop+/s/	79 (26)	7	4	18
Word-final nasal+stop	57 (42)	6	2	14
Word-initial stop+/l/	50 (35)	3	5	11
Word-initial /s/+stop	45 (37)	4	3	11
Word-final /s/+stop	37 (25)	1	5	7
Word-initial /s/+nasal	33 (41)	2	3	7
Word-initial stop+/ɹ/	46 (27)	0	6	6

acceptable pronunciation of *drum* /dɹʌm/, and [kwɑk] was considered an acceptable pronunciation of *clock* /klɑk/. Note that substitutions that did not match the child's singleton productions were counted as errors, e.g. *swing* /swɪŋ/ pronounced as [fwɪŋ] was counted as an error, unless the child also pronounced word-initial singleton /s/ as [f].

A total of 645 word tokens of the shape CCV(C) and 429 word tokens of the shape (C)VCC were analysed. Each child contributed between 69 and 113 word tokens (mean = 90 tokens) and between 29 and 43 different word types (mean = 39) to the analysis. Most of the test items were produced multiple times by each participant. The proportion correct was calculated for each test item. For example, if a child produced the word-initial cluster in the word *plate* /pleɪt/ twice correctly and once incorrectly, this item received a score of 0·67. Thus, each test item contributed equally to the word-final analysis, regardless of the number of times that it had been produced.

There was no difference in the percent correct for data collected on Day 1 (33%) and Day 2 (33%). There was also no difference in the percent correct for spontaneous productions (34%) and imitations (32%). Further analyses therefore collapsed over these two factors.

RESULTS

The percent correct on each cluster type averaged over all 12 participants is shown in the second column of Table 2. As expected, overall performance was better on word-final clusters, with the best performance on nasal+/z/ and stop+/s/ clusters. Note, however, that this raw percentage measure is potentially misleading since there are a number of different ways of achieving this result. For example, a few children can produce a particular cluster very accurately, or many children can produce that cluster with mediocre accuracy. A more informative overall measure of accuracy is to select a particular threshold, and if children score over this threshold, they are said to have 'acquired' a particular cluster. Table 2 therefore also indicates the number of children who produced clusters with at least 75% accuracy for each cluster type and also those who scored between 50 and 74%. We then arrived at a word-final accuracy score for each cluster type by weighting the number of children who scored at least 75% by a factor of two and adding this to the number of children who scored between 50 and 74%. As can be seen from Table 2, overall accuracy on word-final clusters is better than on word-initial clusters with the one exception of word-final /s/+stop clusters. In particular, performance on word-final nasal+/z/ and stop+/s/ clusters is extremely high. These findings are consistent with previous research indicating earlier acquisition of word-final consonant clusters.

To evaluate the hypotheses outlined above regarding possible explanations for the earlier acquisition of word-final clusters, we compared performance on pairs of clusters that were matched for segmental material and sonority profile: (1) word-initial /s/+stop clusters vs. word-final stop+/s/ clusters and word-final /s/+stop clusters, and (2) word-initial /s/+nasal clusters vs. word-final nasal+/z/ clusters.

For all the comparisons tested below, a paired samples t test was applied to the mean proportion of correct productions averaged over all 12 participants for each cluster type. Proportions were normalized by arcsine transformation for the statistical analyses. Means are presented as untransformed proportions. Appendix B provides the untransformed proportions of correctly produced word-initial clusters and word-final clusters by each of the 12 children.

Word-initial /s/+stop clusters vs. word-final stop+/s/ clusters and word-final /s/+stop clusters

First, we compared performance on word-initial /s/+stop clusters (e.g. *school* /skul/) with performance on word-final stop+/s/ clusters (e.g. *box* /bɑks/), where the sonority profile and structure is the same. If structural factors play a role in explaining asymmetries in cluster production we would expect performance on the two cluster types to be equally good. A total of 271 word tokens and 24 word types were analysed. Overall, children were more accurate on word-final stop+/s/ clusters than on word-initial /s/+stop clusters (79% vs. 45%). There was a significant effect of cluster type on production accuracy, $t(11)=2{\cdot}74$, $p<0{\cdot}05$ (2-tailed). Seven of the 12 children correctly produced word-final stop+/s/ clusters at least 75% of the time, while only four of the children correctly produced word-initial /s/+stop clusters with the same degree of accuracy (see Appendix B for proportions correct by each participant). Thus, we see that the better performance on word-final clusters holds for these comparable cluster types. This suggests that the difference in performance must be due to non-structural factors.

We also compared performance on word-initial /s/+stop clusters (e.g. *spoon* /spun/) and word-final /s/+stop clusters (e.g. *wasp* /wɑsp/). These two cluster types are not matched in terms of sonority profile. Word-initial /s/+stop clusters exhibit a marked sonority profile as they do not rise in sonority towards the nucleus. Word-final /s/+stop clusters, on the other hand, show the expected fall in sonority away from the nucleus. The structure of these two cluster types is therefore different, with the word-initial /s/+stop cluster being prosodified as an appendix followed by a singleton onset (Figure 1g) and the word-final /s/+stop cluster being prosodified as a branching coda (Figure 1f). However, both clusters are identical in their sequencing of /s/ followed by a stop consonant. If articulatory factors, regardless of phonetic context, play a role in explaining cluster acquisition asymmetries, we might expect acquisition patterns to be similar on these two cluster types. A total of 242 word tokens and 19 word types were analysed. Overall, children produced word-initial stop+/s/ clusters and word-final /s/+stop clusters with a similar degree of accuracy (45% vs. 38%). There was no significant effect of cluster type on production accuracy for this comparison, $t(11)=0{\cdot}64$, $p=0{\cdot}53$ (2-tailed). This result is consistent with articulatory factors playing a role in explaining the similar performance across these two cluster types.

Word-initial /s/+nasal clusters vs. word-final nasal+/z/ clusters

Next, we compared performance on word-initial /s/+nasal clusters (e.g. *snake* /sneɪk/) with performance on word-final nasal+/z/ clusters (e.g. *beans* /binz/). These were the only other clusters in our study that could be matched for segmental material and sonority profile. A total of 148 word tokens and 11 word types were analysed. Overall, children were more accurate on word-final nasal+/z/ clusters than on word-initial /s/+nasal clusters (85% vs. 33%). There was a significant effect of cluster type on production accuracy, $t(11)=3{\cdot}85$, $p<0{\cdot}001$ (2-tailed). Nine of the 12 children correctly produced word-final nasal+/z/ clusters at least 75% of the time, whereas only 2 of the children correctly produced word-initial /s/ +nasal clusters with this same degree of accuracy. Once again, we found that word-final clusters are produced more accurately than segmentally similar word-initial clusters. We now evaluate possible explanations for these findings.

DISCUSSION

In this section, we evaluate how well each of the four hypotheses (structural, morphological, frequency, and articulatory) explains the asymmetry in the production of word-initial and word-final clusters.

Structure

First we consider whether structural factors can explain the asymmetry in the production of word-initial /s/+stop clusters vs. word-final stop+/s/ clusters. It is generally assumed that the /s/ in both cases is an appendix to the syllable (e.g. Giegerich, 1992). Under this analysis, these clusters are equivalent in terms of structural complexity as both consist of a singleton and appendix. If structural complexity determines production accuracy, then we would expect equivalent performance on word-initial /s/+stop clusters and word-final stop+/s/ clusters. However, this is not what we found, and so we must conclude that structural factors cannot explain the better performance on word-final stop+/s/ clusters.

The structure of word-initial /s/+nasal clusters is controversial. Some researchers have proposed that word-initial /s/+sonorant clusters have the same structure as word-initial /s/+stop clusters, consisting of an appendix plus a singleton (e.g. Kenstowicz, 1994). Others have argued that /s/ +sonorant onset clusters have branching structure because they rise in sonority toward the nucleus (e.g. Giegerich, 1992).The structure of English word-final nasal+/z/ clusters is also controversial. As discussed in the introduction, these have been analysed by some researchers as non-branching (e.g. Selkirk, 1982). According to this analysis, when the vowel is lax, the nasal in word-final nasal+/z/ clusters is syllabified as part of a complex nucleus and the /z/ as a singleton coda (Figure 1c). When the vowel is tense, the nasal is syllabified as a singleton coda and the /z/ as an appendix (Figure 1d). If we assume that word-initial /s/+nasal clusters have branching structure and word-final nasal+/z/ clusters are non-branching, this could explain why two-year olds find the word-initial /s/+nasal clusters more difficult to produce than the structurally more simple word-final nasal+/z/ clusters. Although there is a possible structural explanation for children's more accurate production of word-final nasal+/z/ clusters, a structural account is unable to explain the asymmetry in the production of word-initial /s/+stop clusters and word-final stop+/s/ clusters. It therefore appears that structure cannot provide a unified account for the word-initial vs. word-final asymmetries in coda production by two-year-olds.

Morphology

Next we consider whether morphological factors can explain the asymmetry we found in the production of word-initial /s/+stop clusters and word-final stop+/s/ clusters. If children produce word-final clusters more accurately than word-initial clusters because most word-final clusters are morphologically complex, then we might expect accuracy on the morphologically complex *ducks* /dʌks/ to be better than on the morphologically simple *box* /bɑks/. The test items included only a single monomorphemic word with a final stop + /s/ cluster: *box* /bɑks/, although *socks, chicks*, and *fox* were produced (spontaneously) by one or two children. Averaging over the 10 children who attempted both *ducks* /dʌks/ and *box* /bɑks/, we found that accuracy was very similar on these two items (62 and 63%, respectively). Furthermore, there was a very high correlation between accuracy on *box* /bɑks/ and accuracy on *ducks* /dʌks/, $r=0{\cdot}97$, $p<0{\cdot}001$. Note that the proportion correct for word-final /ks/ clusters is somewhat lower than for word-final stop + /s/ clusters overall (63% vs. 79%). This was because two children (LIY and NAM) had difficulty producing /ks/ clusters, but not /ts/ or /ps/ clusters. Both children produced *ducks* as [dʌts], LIY produced *box* as [bɑts], and NAM produced *box* as [bɑk]. Because these production difficulties were specific to /ks/ clusters, we did not collapse performance on bimorphemic word-final /ps/, /ts/, and /ks/ clusters.

All the target words in this study with word-final nasal + /z/ clusters were morphologically complex. It is therefore impossible to evaluate the possible contribution of morphology for these clusters.

Based on this admittedly small data set, it would appear that production accuracy on word-final consonant clusters is not related to morphological complexity. It therefore seems unlikely that the positional asymmetry for cluster production can be explained by differences in morphological structure. We explore these issues further in Study 2 with longitudinal data from two of the participants from Study 1.

Frequency

We also investigated the possibility that frequency plays a role in the advantage for word-final clusters. To test this hypothesis, we examined the frequency of different cluster types by position (word-initial vs. word-final) in a large sample of English child-directed speech spoken by parents, caregivers, and experimenters to preschoolers learning American English. These utterances form a representative sample of the speech that children are typically exposed to (e.g. dinner table talks, activities of free plays, and storytelling). We analysed child-directed speech from both the Brown corpus (1973) and the Bernstein-Ratner corpus (1982). The original transcripts are available from http://childes.psy.cmu.edu (MacWhinney, 2000). The three children in the Brown corpus were Adam (2;3–4;10), Eve (1;6–2;3), and Sarah (2;3–3;5). The Bernstein-Ratner corpus includes speech from nine mothers to their daughters. These mother–child dyads were taped three times over a period of 4–5 months and the children ranged in age from 1;1 to 1;9 at the time of the first taping.

From this combined corpus of child-directed speech, we extracted all word tokens containing biconsonantal clusters at word edges, yielding a

TABLE 3. *Frequency of biconsonantal cluster types in child directed speech*

Cluster type	Frequency (%)
Word-final nasal + /z/	3
Word-final stop + /s/	20
Word-final nasal + stop	31
Word-initial stop + /l/	6
Word-initial /s/ + stop	7
Word-final /s/ + stop	5
Word-initial /s/ + nasal	1
Word-initial stop + /ɹ/	12
Others	15

total of 63 686 consonant clusters. This provides an estimate of the number of times a child hears a particular cluster regardless of the number of word types in which it occurs. There was a striking differences in the relative frequencies of word-initial vs. word-final consonant clusters, with word-final clusters accounting for 67% of all consonant clusters and word-initial clusters accounting for only 33%. Thus, it is possible that children are sensitive to the frequency of clusters in word-final position at the phonotactic level. That is, they may be aware that many more word tokens end with two consonants than begin with two consonants. However, it is difficult to see how this awareness is translated into production accuracy. If there is a direct relationship between phonotactic frequency and production, then we would expect relatively good accuracy on all word-final clusters. However, this is not what we find.

Frequency is also unable to explain production accuracy when we look at clusters by sonority type. Table 3 provides a complete list of the frequencies in child directed speech for each of the cluster types elicited in the experimental task. These frequencies were calculated as a proportion of all biconsonantal clusters in word-initial and word-final positions. Word-final stop + /s/ clusters are one of the most frequent cluster types in child directed speech, accounting for 20% of all biconsonantal clusters in word-initial and word-final positions. This is consistent with the high accuracy with which these clusters were produced by the children in our study. However, word-final nasal + /z/ clusters account for only 3% of all biconsonantal clusters in child directed speech. If the frequency with which children hear a particular cluster type in the ambient language influences production accuracy, then we would expect accuracy on final nasal + /z/ clusters to be rather poor. Our results show that children were in fact very accurate at producing word-final nasal + /z/ clusters. Thus, the frequency of individual clusters in child-directed speech does not reliably predict the accuracy with which these clusters are produced.

Articulation

Finally, we consider whether articulatory factors play a role in explaining better performance on word-final clusters. We consider first the suggestion that some sequences of consonants are easier to produce than others because of their phonetic context. Performance on word-initial /s/+stop clusters was found to be much less accurate than on word-final stop+/s/ clusters, and similarly word-initial /s/+nasal clusters were produced less accurately than word-final nasal+/z/ clusters. This may be because /s/ and /z/ are easier to produce at the end of an utterance than they are at the beginning. This idea is supported by data from typically developing children learning English which show that fricatives are produced in word-final position before they are produced in word-initial position (e.g. Edwards, 1978). Note that, in our study, accuracy on word-final /s/+stop clusters, as in *toast* /toʊst/, was relatively poor. This suggests that /s/ in a cluster is easy to produce only if it is also word-final in that cluster. Interestingly, 8 of the 12 children in our study made metathesis errors when attempting word-final /s/+stop clusters (e.g. *wasp* /wɑsp/ was pronounced as /wɑps/). These metathesis errors constituted 22% ($n=23$) of children's attempted word-final /s/+stop clusters and reflect a strong preference for /s/ to be at the right edge of the word.

As an alternative articulatory account, we consider the possibility that certain sequences of consonants are more difficult to articulate than other sequences, regardless of phonetic context. Consistent with this account is our finding that accuracy on word-initial and word-final /s/+stop clusters was not significantly different. Unfortunately, there are no other sequences of consonants that occur in both word-initial and word-final position making this alternative articulatory account difficult to disprove.

Additional support for an articulatory account comes from the accuracy patterns for nasal+stop clusters. Notice that although the overall proportion for these clusters was 57%, six children produced these clusters with at least 75% accuracy while four scored very close to 0% accuracy. Three of these four children were able to produce word-final nasal+/z/ and word-final stop+/s/ clusters with a high degree of accuracy, but sequencing nasal+stop clusters in word-final position appears to give them particular difficulty. Nasal+stop clusters are articulatorily problematic because of a conflict between producing the nasal consonant, which requires relaxation of the palatal levator, and producing the stop consonant, which requires these muscles to contract. It seems likely that the four children with 0% accuracy on nasal+stop clusters have not yet mastered the fine motor control necessary for articulating nasal+stop clusters.

Further evidence that articulatory ease plays a role in cluster production at a more general level comes from substitution errors. Substitutions in cluster production occur when two consonants are produced, but one or both consonants are replaced. The majority of these errors can be predicted from errors on corresponding singletons, e.g. children who glide liquid singletons, also glide liquids in clusters. However, in our data, approximately one-third of substitutions could not be predicted from singleton production. Of these unpredictable substitutions, 60% (80/133) appear to be motivated by a preference for clusters where both members share the same place of articulation (e.g. *grapes* pronounced as [beɪts], *blocks* pronounced as [bɑts]). However, only 7% (9/133) of substitutions involved clusters with the same place of articulation being substituted for clusters which did not share the same place of articulation (e.g. *nest* pronounced as [nɛks]). This preference for clusters where both members share the same place of articulation is also apparent in the accuracy patterns within a cluster type. For example, one child (LIY) could produce the initial cluster in *snail* and *snake*, but not the cluster in *smoke*. Two other children (POR and MYA) could produce the initial cluster in *stick* and *star*, but not the clusters in *spoon* or *scarf*. These findings provide further support for the idea that some sequences of consonants are easier to articulate than others.

Summary

The results from Study 1 show that two-year-olds are most accurate at producing word-final nasal+/z/ and word-final stop+/s/ consonant clusters. This suggests that these particular clusters are easier to produce, and probably the earliest acquired. Appealing to structural factors alone cannot account for these findings. Structural arguments would predict equal performance on word-initial /s/+stop clusters and word-final stop+/s/ clusters. However, we found that children perform significantly better on word-final clusters. Frequency explanations for the positional asymmetry in cluster production were also unsatisfactory in explaining our results. Frequency predicts that accuracy should be high on high frequency clusters and low on low frequency clusters. Although performance on high-frequency clusters was generally good, word-final nasal+/z/ clusters, which are low in frequency, were produced with much higher accuracy than a frequency account would predict.

Furthermore, we found no significant difference in performance on morphologically complex vs. morphologically simple stop+/s/ coda clusters. However, given the morphologically complex nature of many of the clusters used in the picture identification task in this study, it was not possible to truly evaluate the contributions of morphology to cluster production accuracy. The motivation for Study 2 was therefore to explore more fully the possible contribution of morphology to the production of word-final clusters.

STUDY 2

METHOD

Participants

Study 2 examined the production of monomorphemic and bimorphemic word-final clusters in the naturalistic, spontaneous speech of two of the children who participated in Study 1, a girl (NAI) and a boy (EVA). The data form part of the Demuth Providence Corpus, consisting of mother–child spontaneous speech interactions from six typically developing English-speaking children between 0;11–3;0.

Data transcription and analysis

Digital audio and video recordings were collected in the children's homes for approximately one hour every week for NAI, and one hour every two weeks for EVA from the time they produced their first words for the following two years. The data were transcribed in CHAT format which included broad phonetic transcription of the children's utterances (MacWhinney, 2000, http://childes.psy.cmu.edu/manuals/CHAT). Ten percent of the child utterances were retranscribed by another researcher. Reliability between the two transcribers averaged 85%.

Each of the participant's transcriptions was then searched for relevant monomorphemic and bimorphemic clusters. To be as comparable as possible with Study 1, we restricted all word tokens to monosyllabic nouns with word-final clusters, and all bimorphemic nouns to plurals. Since the purpose of Study 2 was to address the possible effect of morphology on the acquisition of word-final clusters, we focused on the high-frequency word-final stop+/s/ clusters. Productions of word-final nasal+/z/ clusters in monomorphemic words were extremely rare, so we were unable to compare accuracy on monomorphemic and bimorphemic words with this cluster in word-final position. Excluded from the analysis were cases where word-final clusters were followed by a vowel-initial word. In such instances, it was possible that the child resyllabified all or part of the cluster as an onset to the following word (e.g. *mix it*). Also excluded were cases where the plural status of the referent was not clear. The remaining target clusters were coded for production accuracy using the same criteria used in Study 1.

RESULTS

Before the age of 1;3.12, NAI attempted no words with word-final stop+/s/ clusters. Between the ages of 1;3.12 and 1;5.6, NAI attempted 36 tokens of two words (*box, Max*) with monomorphemic word-final stop+/s/ clusters, producing them accurately 86% of the time. During this same age range, she attempted 115 tokens of 12 words (*cats, rocks, books, blocks, cups,* *grapes, socks, blocks, boats, socks, mics, oats*) with plural stop + /s/ clusters, producing them accurately 93% of the time. Accuracy on monomorphemic and on bimorphemic word-final clusters was not significantly different, $\chi^2_{(1)} = 1{\cdot}67$, $p > 0{\cdot}1$.

In the sessions recorded over the next year (ages 1;5,12–2;7.13), NAI maintained a high level of accuracy for both monomorphemic and bimorphemic final clusters. During this time, NAI attempted 17 monomorphemic and 138 bimorphemic cluster tokens. Because, there were large chunks of time when no monomorphemic word-final clusters were attempted, we compared accuracy across monomorphemic and bimorphemic clusters on just those sessions where both types of cluster were attempted. NAI attempted 17 tokens of 4 words (*Max*, *box*, *six*, *fox*) with monomorphemic stop + /s/ final clusters, producing them accurately 88% of the time. She attempted 20 tokens of 9 words (*rocks*, *blocks*, *books*, *socks*, *lips*, *nuts*, *ducks*, *hats*, *books*) with plural stop + /s/ clusters, producing them accurately 85% of the time. For this second time period, accuracy on monomorphemic and bimorphemic final clusters was not significantly different, $\chi^2_{(1)} = 0{\cdot}08$, $p > 0{\cdot}1$. Thus, NAI shows no effect of morphology on her accuracy with word-final stop + /s/ clusters.

Between the ages of 1;2.2 and 1;4.10, EVA attempted 12 tokens of 6 words (*blocks*, *lights*, *steps*, *ducks*, *plates*, *hats*) with bimorphemic clusters with limited success. His accuracy on these clusters during this time was 33%. At 1;4.26, EVA attempted his first monomorphemic final cluster producing the word *fox* 16 times in the same session. His accuracy on *fox* during this session was 81%. EVA produced no bimorphemic stop + /s/ clusters in this session, but in the following session (aged 1;5.16), he produced 5 tokens of 2 words (*straps*, *lights*) with bimorphemic clusters with 100% accuracy. EVA did not produce any more bimorphemic clusters until 1;6.20 when he produced 8 tokens of 3 words (*shapes*, *trucks*, *blocks*) with 36% accuracy.

EVA did not attempt any more monomorphemic final clusters again until 1;11.22. From this time until 2;6.10, EVA attempted 8 tokens of 2 words (*box*, *six*) with monomorphemic final stop + /s/ clusters with 50% accuracy. Accuracy on bimorphemic clusters was much higher during this time. Between 1;11.22 and 2;6.10, EVA produced 36 tokens of 10 words (*rocks*, *brakes*, *trucks*, *tracks*, *shapes*, *stripes*, *boots*, *bricks*, *cracks*, *roots*) with bimorphemic clusters with 92% accuracy. It is somewhat surprising that from age 1;11.22, EVA's production accuracy on monomorphemic clusters deteriorated while accuracy on bimorphemic clusters remained consistently high. It is possible that as EVA's utterances became longer and more complex, greater processing demands caused monomorphemic clusters to be sacrificed whereas the same did not occur with the semantically important clusters in bimorphemic words.

To summarize, there is no strong evidence that these two children are more accurate at producing word-final clusters when they are morphologically complex. NAI produced both monomorphemic and bimorphemic words with final stop + /s/ clusters with a high degree of accuracy from the first time she attempted these words. EVA's acquisition of stop + /s/ clusters is more difficult to interpret. For this child, data are sparse and accuracy varies widely across sessions, making it difficult to decide which sessions to combine for meaningful comparison. However, it is worth noting that EVA's accuracy on monomorphemic clusters was relatively high when his utterances were one or two words in length. The responses we received in the experimental task were similarly almost all single word responses. When EVA participated in the experimental task at age 1;7.18, all his attempts at targets with stop + /s/ clusters (*box* (10 tokens), *ducks* (4 tokens), *cups* (1 token), *boots* (1 token)) were accurately produced.

An alternative explanation for the similarity in the accuracy patterns for monomorphemic and bimorphemic clusters is that children do not know that words like *ducks* are morphologically complex and instead treat plurals as unanalyzable wholes. However, the longitudinal data show that both NAI and EVA use the singular and plural forms of the same root in the same session. For example, at age 1;4.10, EVA uses both singular and plural forms for *plate* and *hat*. For *plate*, it is very clear that EVA has productive use of the plural. He identifies a particular *purple plate* by referring to ['pʊpoʊ 'peɪt], and then shortly afterwards he mentions *two plates* ['tu 'pits]. At age 1;7.14, EVA makes reference to both singular and plural forms for *ducks*, *trucks*, and *books*.

Like EVA, NAI shows productive use of the plural at an early age. At age 1;3.12, she produces both *cat* and *cats*, and at 1;4.3, she uses both singular and plural forms of *rocks*, *blocks* and *cups*. At age 1;4.18, it is clear that NAI understands how to use the singular and plural forms of nouns appropriately. In this session, NAI refers to a specific book as *my llama book* [mɛ 'jæmə 'bʊk], and then later in the session in response to her mother's question, *What do we do at bedtime?*, NAI answers *books* ['bʊks]. These data suggest it is unlikely that the similarity in production patterns for monomorphemic and bimorphemic clusters occurs because children fail to analyse plural clusters into their component morphemes.

The results from the longitudinal study confirm the finding of Study 1 that accuracy on word-final stop + /s/ clusters is very similar for both monomorphemic and bimorphemic clusters, at least for single word responses. This suggests that greater accuracy in the experimental task on word-final stop + /s/ clusters (e.g. *cups* /kʌps/) compared to word-initial /s/ + stop initial clusters (e.g. *spoon* /spun/) is unlikely to be due to differences in morphological structure.

GENERAL DISCUSSION

The purpose of this paper was to explore possible explanations for the fact that word-final clusters tend to be acquired before word-initial clusters. Word productions elicited from two-year-olds during a picture identification task confirmed that there was better performance on most word-final clusters. We found an asymmetry between word-initial /s/+stop and /s/+nasal clusters compared to word-final stop+/s/ and nasal+/z/ clusters, with the word-final clusters being more accurately produced. These findings raise questions about the factors that contribute to early cluster production accuracy.

One explanation we considered for this asymmetry is that word-final clusters have simpler structure, and these simpler structures are easier to produce. However, structural differences cannot account for the asymmetry we found in the production of word-initial /s/+stop clusters and word-final stop+/s/ clusters since it is generally assumed that both of these clusters consist of a singleton consonant and an appendix.

We also considered a morphological explanation for the asymmetry in the production of word-initial and word-final clusters. We found that participants were just as likely to accurately produce word-final stop+/s/ clusters regardless of whether they were morphologically simple or morphologically complex. For example, the production of morphologically complex *ducks* /dʌks/ was just as accurate as the production of morphologically simple *box* /bɑks/. It is therefore unlikely that better performance on *cups* /kʌps/ than on *spoon* /spun/ is due to differences in their morphological structure. Further examination of longitudinal spontaneous production data from two of the children in the experimental study showed that there was no bias toward more accurate production of bimorphemic clusters, with one of the children showing no significant difference between the two, and the other child showing variable performance on both. It therefore appears that morphological factors cannot explain better performance on word-final clusters.

The frequency with which a particular cluster appears in child-directed speech also failed to provide a satisfactory explanation for the positional asymmetry in cluster production. We found that the frequency of individual word-final clusters was a poor predictor of performance. In particular, frequency cannot explain why nasal+/z/ clusters, which occur in only 3% of biconsonantal clusters in child directed speech, are produced with higher accuracy in this study than nasal+stop clusters, which constitute 31% of the clusters children typically hear, the highest frequency of any word-final cluster.

We have argued that articulatory factors provide the best explanation of the asymmetry in the production of word-initial and word-final clusters. As discussed earlier, studies have shown that singleton fricatives are easier to produce at the ends of words than at the beginning of words. It is therefore possible that the articulatory advantage for word-final fricatives carries over to the production of consonant clusters ending with /s/ and /z/. Perhaps this can help explain the better performance on both word-final nasal+/z/ and stop+/s/ clusters compared with word-final /s/+stop clusters. We have also discussed the fact that articulatory coordination problems may cause low production accuracy on word-final nasal+stop clusters for some children. We conclude that articulatory factors best capture the asymmetries in cluster production found in this study.

CONCLUSION

This study explored two-year-old English-speakers' productions of segmentally similar word-initial and word-final consonant clusters. In keeping with other studies, it found earlier acquisition of word-final clusters. In addition, it found that some word-final clusters (nasal+/z/ and stop+/s/) were produced more accurately than others (nasal+stop and /s/+stop). Neither structural, morphological, nor frequency accounts provide a satisfactory explanation of these findings. Instead, an articulatory explanation best captures the production patterns found in this study. We hope that this study will stimulate further exploration of these issues in other languages, where the possible interplay of structural, morphological, frequency-based and articulatory constraints on early production can be addressed. Such comparative study is critical for furthering our understanding of phonological development at the levels of the segment, the syllable, and the word.

REFERENCES

Barlow, J. (2001). The structure of /s/-sequences: evidence from a disordered system. *Journal of Child Language* **28**, 291–324.

Bennett, C. W. & Ingle, B. H. (1984). Production of /s/ as a function of word frequency, phonetic environment, and phoneme position. *Journal of Communication Disorders* **17**, 361–9.

Bernstein-Ratner, N. (1982). *Acoustic study of mothers' speech to language-learning children: an analysis of vowel articulatory characterstics*. Unpublished doctoral dissertation, Boston University.

Berry, M. F. & Eisenson, J. (1956). *Speech disorders: principles and practices of therapy*. New York: Appleton.

Brown, R. (1973). *A first language: the early stages*. Cambridge, MA: Harvard.

Chin, S. & Dinnsen, D. (1992). Consonant clusters in disordered speech: constraints and correspondence patterns. *Journal of Child Language* **19**, 259–85.

Clements, G. N. (1990). The role of the sonority cycle in core syllabification. In J. Kingston & M. Beckman (eds), *Papers in laboratory phonology I: between the grammar and physics of speech*. New York: Cambridge University Press.

Clements, G. N. & Keyser, S. J. (1983). *CV phonology: a generative theory of the syllable* (Linguistic Inquiry Monograph 9). Cambridge MA: MIT Press.

Demuth, K. (2001). Prosodic constraints on morphological development. In J. Weissenborn & B. Höhle (eds), *Approaches to bootstrapping: phonological, syntactic and neurophysiological* *aspects of early language acquisition. Language Acquisition and Language Disorders Series* **24**, 3–21. Amsterdam: John Benjamins.

Edwards, M. L. (1978). *Patterns and processes in fricative acquisition: longitudinal evidence from six English-learning children.* Unpublished doctoral dissertation, Stanford University, California.

Gallagher, T. M. & Shriner, T. H. (1975*a*). Articulatory inconsistencies in the speech of normal children. *Journal of Speech and Hearing Research* **18**, 168–75.

Gallagher, T. M. & Shriner, T. H. (1975*b*). Contextual variables related to inconsistent /s/ and /z/ production. *Journal of Speech and Hearing Research* **18**, 623–33.

Giegerich, H. (1992). *English phonology: an introduction.* Cambridge, UK: CUP.

Gierut, J. (1999). Syllable onsets: clusters and adjuncts in acquisition. *Journal of Speech, Language, and Hearing Research* **42**, 708–26.

Gnanadesikan, A. (2004). Markedness and faithfulness constraints in child phonology. In R. Kager, J. Pater & W. Zonneveld (eds), *Fixing priorities: constraints in phonological acquisition.* Cambridge, UK: CUP.

Goad, H. & Rose, Y. (2004). Input elaboration, head faithfulness and evidence for representation in the acquisition of left-edge clusters in West Germanic. In R. Kager, J. Pater & W. Zonneveld (eds), *Fixing priorities: constraints in phonological acquisition.* Cambridge, UK: CUP.

Halle, M. & Vergnaud, J.-R. (1980). Three dimensional phonology. *Journal of Linguistic Research* **1**, 83–105.

House, A. S. (1981). Reflections on a double negative: misarticulation and inconsistency. *Journal of Speech and Hearing Research* **24**, 98–103.

Kahn, D. (1976). *Syllable based generalizations in English phonology*. Unpublished doctoral dissertation. MIT.

Kaye, J., Lowenstamm, J. & Vergnaud, J. (1990). Constituent structure and government in phonology. *Phonology* **7**, 193–231.

Kenstowicz, M. (1994). *Phonology in generative grammar*. Cambridge, MA: Blackwell.

Kent, R. D. (1982). Contextual facilitation of correct sound production. *Language, Speech, and Hearing Services in Schools* **13**, 66–76.

Leonard, L. B. & Ritterman, S. I. (1971). Articulation of /s/ as a function of cluster and word frequency of occurrence. *Journal of Speech and Hearing Research* **14**, 476–85.

Levelt, C., Schiller, N. & Levelt, W. (2000). The acquisition of syllable types. *Language Acquisition* **8**, 237–64.

Lleó, C. & Prinz, M. (1996). Consonant clusters in child phonology and the directionality of syllable structure assignment. *Journal of Child Language* **23**, 31–56.

MacWhinney, B. (2000). *The CHILDES project: tools for analyzing talk. 3rd edition. vol. 2: the database.* Mahwah, NJ: Erlbaum.

Mazza, P. L., Schuckers, G. H. & Daniloff, R. G. (1979). Contextual-coarticulatory inconsistency of /s/ misarticulation. *Journal of Phonetics* **7**, 57–69.

McLeod, S., van Doorn, J. & Reed, V. (2001). Consonant cluster development in two-year-olds: general trends and individual difference. *Journal of Speech, Language, and Hearing Research* **44**, 1144–71.

Moore, W. H., Burke, J. & Adams, C. (1976). The effects of stimulability on the articulation of /s/ relative to cluster and word frequency of occurrence. *Journal of Speech and Hearing Research* **9**, 458–66.

Munson, B. (2001). Phonological pattern frequency and speech production in adults and children. *Journal of Speech, Language, and Hearing Research* **44**, 778–92.

Ohala, D. (1999). The influence of sonority on children's cluster reductions. *Journal of Communication Disorders* **32**, 397–422.

Pater, J. & Barlow, J. (2003). Constraint conflict in cluster reduction. *Journal of Child Language* **30**, 487–526.

Selkirk, E. (1982). The Syllable. In H. van der Hulst & N. Smith (eds), *The structure of phonological representations – Part II*. Dordrecht, The Netherlands: Foris.

Slobin, D. (1973). Cognitive prerequisites for the development of grammar. In C. Ferguson & D. Slobin (eds), *Studies of Child Development*. New York: Holt, Rinehart & Winston, Inc.
Smit, A. (1993). Phonologic error distributions in the Iowa-Nebraska Articulation Norms Project: word-initial consonant clusters. *Journal of Speech and Hearing Research* **36**, 931–47.
Smit, A. B., Hand, L., Freilinger, J. J., Bernthal, J. E. & Bird, A. (1990). The Iowa Articulation Norms Project and its Nebraska replication. *Journal of Speech and Hearing Disorders* **55**, 779–98.
Stoel-Gammon, C. (1987). Phonological skills of 2-year-olds. *Language, Speech, and Hearing Services in Schools* **18**, 323–9.
Stoel-Gammon, C. & Buder, E. (1999). Vowel length, post-vocalic voicing and VOT in the speech of two-year olds. *Proceedings of the XIIIth International Conference of Phonetic Sciences* **3**, 2485–8.
Templin, M. (1957). *Certain language skills in children: their development and interrelationships* (Monograph Series No. 26). Minneapolis: University of Minnesota, The Institute of Child Welfare.
Watson, M. & Scukanec, G. (1997). Profiling the phonological abilities of 2-year olds: a longitudinal investigation. *Child Language Teaching and Therapy* **13**, 3–14.
Zamuner, T., Gerken, L. A. & Hammond, M. (2004). Phonotactic probabilities in young children's speech production. *Journal of Child Language* **31**, 515–36.

APPENDIX A

EXPERIMENTAL MATERIALS BY CLUSTER TYPE

Word-initial clusters

/s/ + stop	/s/ + nasal	stop + /l/	stop + /ɹ/
spoon	smile	plate	prize*
spot*	smoke	plane	bread
stay*	smash*	play*	bridge
stick	snake	please*	brush
stairs	snail	plum*	train
star	snow*	black	truck
sting*		blue	tree
stop*		block	drum
stuck*		clock	draw*
stuff*		clown	dress*
steam*		cloud*	crab
scarf		clean*	green
school			
skirt			

Word-final clusters

stop + /s/	nasal + /z/	nasal + stop	/s/ + stop
cups	drums	lamp	wasp
boots	beans	jump*	toast
nuts*	pens*	tent	nest
cats*	things*	paint	fast*

Appendix A (*Cont.*)

Word-final clusters			
stop + /s/	nasal + /z/	nasal + stop	/s/ + stop
lots*	wings*	mint*	desk
box		pink	
ducks		ink*	
socks*		hand	
chicks*		sand	
fox*		end*	

* Words marked by an asterisk were not elicited by the experimenter, but were spontaneously produced by one or more children during an experimental session.

APPENDIX B

PROPORTION CORRECT BY PARTICIPANT AND CLUSTER TYPE

	Word-initial clusters			
Participants	/s/ + stop	/s/ + nasal	stop + /l/	stop + /ɹ/
LIL	85	67	100	55
SOP	86	100	71	73
NAM	75	50	61	71
NAH	100	0	80	63
NAI	63	100	50	20
MAT	0	0	0	0
EVA	0	0	64	48
LIY	58	67	80	70
POR	50	8	0	0
SAR	0	0	14	42
MYA	20	0	10	7
ALE	11	0	64	37

	Word-final clusters			
Participants	nasal + /z/	stop + /s/	nasal + stop	/s/ + stop
LIL	100	100	100	54
SOP	100	100	86	25
NAM	100	80	78	75
NAH	100	67	94	58
NAI	100	100	67	0
MAT	100	100	85	0
EVA	92	100	0	37
LIY	63	67	0	37
POR	100	88	100	67
SAR	67	67	70	50
MYA	100	71	0	25
ALE	0	10	6	13