Onset/Coda Asymmetries in the Acquisition of Clusters

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1. Introduction

The introduction of Optimality Theory (Prince & Smolensky, 1993) has led to renewed interest in the acquisition of prosodic structures, with particular attention given to the development of syllables and prosodic words (Demuth 1995; Gnanadesikan, in press; Pater, 1997). Many of these studies investigate the phonological constraints underlying children's early grammars and how these constraints change systematically over time. The acquisition of consonant clusters is especially interesting, being one of the more marked and later-acquired aspects of syllable structure.

Previous research on the acquisition of consonant clusters in English has focused primarily on onset clusters (e.g., Barlow, 1997; Chin & Dinnsen, 1992; Gierut, 1999; Gnanadesikan, in press; Goad & Rose, 2002; Ohala, 1995; Pater & Barlow, 2002; Smit, 1993). Smit (1993) reports that among normally developing children, reduction of many onset clusters is no longer typical by the age of 3;6. Onset clusters are also particularly difficult for many children with phonological delay, requiring targeted intervention to enhance their production. However, there has been little discussion of how and when coda clusters are acquired.

There has been some research investigating the acquisition of coda clusters in languages other than English. Lleó and Prinz (1996) examined longitudinal data from five German children between the ages 0;9-2;1 years. These children acquired coda clusters several months before onset clusters. Furthermore, coda clusters were more accurately produced than onset clusters, although this difference was not significant. Levelt, Schiller, & Levelt (2000) examined longitudinal data from twelve children learning Dutch (1;0-1;11 years at the outset of their study). They found that nine of the children in their study acquired CVCC syllable structures before CCVC structures, while the remaining

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three children showed the reverse order of acquisition. Thus, there was a tendency in Dutch for final clusters to be acquired before initial clusters.

There are several limitations to these studies. In the Dutch study, /s/-clusters in initial and final position were not considered. Furthermore, a child was said to have "acquired" a particular syllable type if it was produced at least twice in the period under consideration. However, no analysis of variability in cluster production was provided, so it is unclear how many unsuccessful attempts at words with target clusters there might have been. Neither the German nor the Dutch study gives a breakdown of clusters by sonority type, so it is difficult to draw strong conclusions about comparisons between onset and coda clusters.

Despite these limitations, both studies point to the earlier acquisition of coda clusters. This finding is surprising given that singleton codas are more marked than singleton onsets, and tend to be acquired later. This might lead us to expect that complex onsets would develop before complex codas. On the other hand, if we look at the occurrence of clusters cross-linguistically we see that there are languages that permit only complex onsets (e.g., Spanish) and also languages that permit only complex codas (e.g., Finnish). Thus, cross-linguistically, coda clusters are no more marked than onset clusters and so we might expect clusters in onsets and codas to be acquired at the same time.

2. Experiment

The goal of our study was to examine the comparative acquisition of onset and coda clusters in English-speaking children. To do this, we conducted a cross-sectional experimental study with 2-year-olds, an age at which some children show advanced use of clusters and others do not. Because we wished to assess the robustness of individual children's phonological representations, we collected multiple productions of a large number of target clusters differing in sonority type. This allowed us to calculate the number of correctly produced clusters relative to the total number of attempted clusters.

2.1 Participants

The participants were 9 two-year olds (5 girls, 4 boys) from monolingual English-speaking homes. Their mean age was 2;2 years (range: 1;7-2;7). Six additional participants failed to complete the task because of fussiness.

2.2 Procedure

Pictures and toys were used to elicit English target words containing biconsonantal clusters. 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 in two play sessions on consecutive days. Recording each child in two separate sessions allowed

multiple tokens of each cluster type to be collected. Each session lasted between 20-40 minutes and took place either in the child's home or in a quiet room at their daycare center.

2.3 Materials

The test items included 69 real English words with target CC clusters in stressed syllables. Each child was presented with 44 test items with initial CC clusters and 25 test items with final CC clusters. The following cluster types were targeted:

onset clusters: /s/+C, C+/l/, C+/ɹ/, C+/j/, C+/w/

coda clusters: nasal+stop, C+/s,z/, /s/+stop

Coda clusters involving liquids were not targeted. The dialect of English spoken by local Rhode Islanders has no /ɹ/ in coda position. Furthermore, postvocalic /l/ is often pronounced by young children as a glide making it difficult to transcribe reliably.

2.4 Data transcription

All data were transcribed in IPA by two transcribers. Any differences between the two transcribers were resolved by consensus. If consensus could not be achieved, a third transcriber was consulted, the issue resolved, or the item discarded (less than .5% of the total items).

2.5 Data analysis

A total of 1,674 words with target CC clusters in stressed syllables were analyzed. Each child contributed between 139-228 tokens (mean = 186 tokens) to the analysis. All the 1,674 responses were classified as being produced as either target appropriately (correct), or non-target appropriately (errors). Table 1 gives examples of the types of productions that were classified as non-target appropriate.

Table 1: Examples of productions classified as non-target appropriate

Error type	Target Word		Response
Reduction	glove	/glʌv/	[gʌv]
Substitution	swing	/swɪŋ/	[fwɪŋ]
Coalescence	spoon	/spun/	[fun]
Metathesis	toast	/tost/	[tots]
Deletion	desk	/dɛsk/	[dɛ]

Mismatches in voicing between the target cluster and child's production were not coded as errors. For example, if *pigs* /pɪgz/ was pronounced as [pɪks],

the child was considered to have produced this cluster target-appropriately. Similarly, if the child realized /s/ as [ʃ] or [θ], e.g., *spoon* /spun/ as [ʃpun], or *box* /bɑks/ as [bɑkθ], these mismatches were ignored. Substitutions of /l/ and /ɹ/ by [w] were also classified as target-appropriate, e.g., *drum* /dɹʌm/ as [dwʌm], and *clock* /klɑk/ as [kwɑk].

There was no difference in the percent correct for data collected on Day 1 (33%) and Day 2 (35%). There was also no difference in the percent correct for spontaneous productions (34%) and imitations (34%). Further analyses therefore collapsed over these two factors.

3. Results and Discussion

The main finding of the study was that coda clusters were much more accurately produced than onset clusters (60% vs. 35%) and this difference was highly significant: $\chi^2(1) = 101.39$, $p < .001$. This is shown in Figure 1. This result was somewhat unexpected. Given that singleton codas are more marked than singleton onsets and tend to be acquired later, we might have expected complex onsets to develop before complex codas. Why, then, do these children show earlier acquisition of coda clusters?

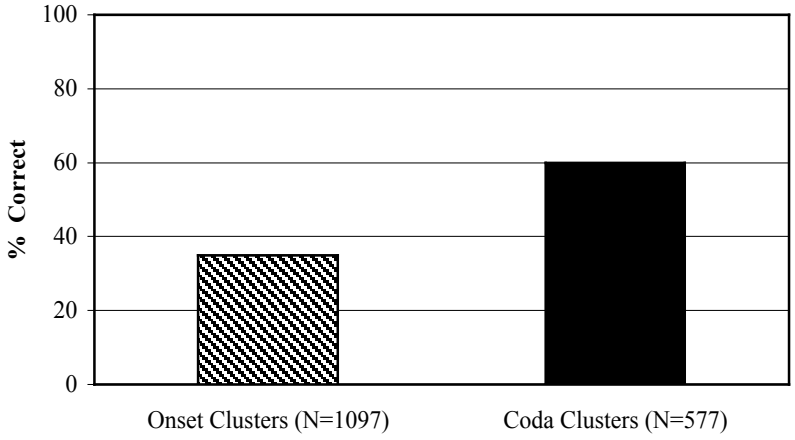

Figure 1: Percentage of onset clusters and coda clusters produced target appropriately

A possible explanation for the more accurate production of coda clusters is that coda clusters may have simpler structure than onset clusters, and these simpler structures may be easier to acquire and/or produce. To test the hypothesis that the onset/coda asymmetry is structural, one would need to

compare performance on /s/+stop onset clusters with stop+/s/ coda clusters. These clusters violate the Sonority Sequencing Principle, and for this reason the /s/ in these clusters is commonly analyzed as extrasyllabic (e.g., Giegerich, 1992). A structural hypothesis predicts that the asymmetry in cluster production should disappear for these cluster types since they have identical non-branching structure in both onsets and codas.

An alternative explanation for the onset/coda asymmetry might be morphological. In English, many word-final clusters contain important morphological information (e.g., *duck-s*), whereas there is no morphological content in onset clusters. Perhaps the presence of these word-final morphemes serves to focus children's attention on the ends of words (cf. Slobin, 1973). It could be that once the English-learning child becomes aware of word-final morphology, this awareness leads to more accurate production of bimorphemic clusters. This would predict better performance on *duck-s* /dʌks/ than on *school* /skul/. Furthermore, it would also predict better performance on bimorphemic clusters than on monomorphemic coda clusters (e.g., *duck-s* /dʌks/ vs. *box* /bɑks/).

On the other hand, perhaps frequency plays a role in the earlier acquisition of coda clusters. Levelt et al. (2000) have shown a correlation 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 could be that English-speaking children produce coda clusters more accurately than onset clusters because they occur more frequently in the ambient language.

Having established that children find it easier to produce coda clusters than onset clusters, we then compared performance on various subtypes of onset and coda clusters. This allowed us to evaluate these different hypotheses regarding the onset/coda asymmetry.

3.1 Analysis of Cluster Types

To evaluate the three hypotheses outlined above (structural, morphological, and frequency-based) we compared performance on clusters that were matched for segmental material and sonority profile. First, we compared performance on /s/+stop onsets with performance on stop+/s/ codas. That is, we wanted to compare accuracy on the initial cluster of a word like *school* /skul/ with accuracy on the final cluster of a word like *box* /bɑks/.

Children were more accurate on stop+/s/ coda clusters than on /s/+stop onset clusters (74% vs. 38%) and this difference was highly significant: $\chi^2(1) = 59.93$, $p < .001$. Figure 2 shows the percentage of correctly produced /s/+stop onset clusters and stop+/s/ coda clusters by each of the 9 children. Seven of the 9 children correctly produced stop+/s/ coda clusters at least 70% of the time, while only 3 of the children correctly produced /s/+stop onset clusters with the same

degree of accuracy. Thus, we see that the coda cluster advantage holds for these comparable cluster types.

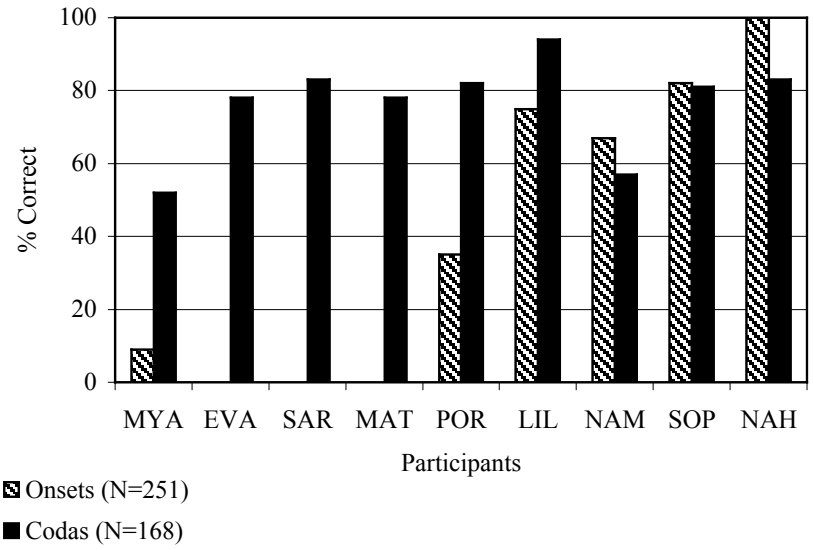

Figure 2: Percentage of /s/+stop onset clusters and stop+/s/ coda clusters produced target appropriately

It is generally assumed that /s/ in both these onset and coda clusters is an appendix to the syllable (e.g., Giegerich, 1992). Others have argued that /s/+stop onsets and stop+/s/ codas are complex segments occupying a single skeletal slot and thus have the same structure as affricates (Fudge, 1969; Selkirk, 1982). Under both of these analyses, /s/+stop onsets and stop+/s/ codas are equivalent in terms of structural complexity. If there is a correlation between structure and production accuracy, then we would expect equivalent performance on /s/+stop onsets and stop+/s/ codas. Thus, structure cannot explain the better performance on stop+/s/ coda clusters.

Next we consider whether morphology can explain the asymmetry we find with the production of /s/+stop onsets and stop+/s/ codas. A comparison of accuracy on the morphologically simple *box* /bɑks/ with accuracy on the morphologically complex *duck-s* /dʌks/ reveals that performance was not significantly different (81% and 72%, respectively): $\chi^2(1) = .416$, $p < .5$. This suggests that greater accuracy on stop+/s/ codas (e.g., *cups* /kʌps/) compared to /s/+stop onsets (e.g., *spoon* /spun/) is unlikely to be due to differences in morphological structure. However, this does not preclude a morphological bootstrapping strategy where general awareness of word-final morphology

boosts accuracy on words with morphologically simple final clusters, such as *box* /bɑks/.

Perhaps frequency plays a role in the coda cluster advantage. To test this hypothesis we examined the frequency of different cluster types by position (onset vs. coda) in a large sample of child-directed speech. These included the Adam, Eve, and Sarah files from the CHILDES database (MacWhinney, 1996) augmented with some of our own longitudinal data from 2 children between the ages of 0;11 and 1;6 years. We extracted all biconsonantal clusters at word edges in stressed syllables, yielding at total of 55,139 CC clusters.

When we consider all onset and coda CC clusters in our database of child-directed speech, we find a striking difference in their relative frequencies. The majority, 74%, are coda clusters. We find a similar frequency difference when we look just at /s/+stop onset clusters and stop+/s/ coda clusters. Of the 55,139 CC clusters extracted from child-directed speech, stop+/s/ codas make up 22% while /s/+stop onsets make up only 5%. Thus, there is a positive correlation between the frequency of clusters in child-directed speech and their higher accuracy in production. This is consistent with the view that the frequency of particular structures in the input influences their order of acquisition.

Summarizing, structural arguments would predict equal performance on /s/+stop onsets and stop+/s/ codas, but we find that children perform significantly better on the coda clusters. Furthermore, we find no significant difference in performance on morphologically complex versus morphologically simple stop+/s/ coda clusters. It therefore appears that the difference in the relative frequency of these two cluster types best explains the more accurate production of coda clusters.

Next, we compared performance on /s/+nasal onsets (e.g., *snake* /sneɪk/) with performance on nasal+/z/ codas (e.g., *beans* /binz/). These are the only other clusters in our study that can be matched in onsets and codas for segmental material and sonority profile.

The results show that nasal+/z/ coda clusters were produced more accurately than /s/+nasal onset clusters (84% vs. 21%) and this difference was highly significant: $\chi^2(1) = 46.57$, $p < .001$. Figure 3 shows the percentage of correctly produced /s/+nasal onsets and nasal+/z/ codas by each of the 9 children. Six of the 9 children correctly produced nasal+/z/ coda clusters at least 70% of the time, whereas none of the children correctly produced /s/+nasal onset clusters with this same degree of accuracy. Two of the children did not provide enough data to reliably estimate their production of nasal+/z/ codas; this is indicated in Figure 3 by "?". Once again, we find that coda clusters are produced more accurately than onset clusters.

The structure of /s/+nasal onset clusters is controversial. Kaye, Lowenstamm and Vergnaud (1990) have proposed that both /s/+stop and /s/+sonorant clusters consist of an appendix plus a singleton. Other researchers (e.g., Giegerich, 1992) have argued that /s/+sonorant onset clusters have branching structure because they rise in sonority toward the nucleus. Fikkert

(1994) suggests that children learning to speak Dutch syllabify word-final clusters consisting of a sonorant followed by another consonant as non-branching. Under this analysis, the sonorant is syllabified as part of a complex nucleus and the following consonant is syllabified as a singleton coda. It is possible that children learning English analyze word-final nasal+/z/ clusters in a similar way, with the nasal syllabified as part of a complex nucleus and the /z/ as a singleton coda. If we assume that /s/+nasal onsets have branching structure and nasal+/z/ clusters are non-branching, this could explain why two-year olds find /s/+nasal onset clusters more difficult to produce than the structurally more simple nasal+/z/ clusters.

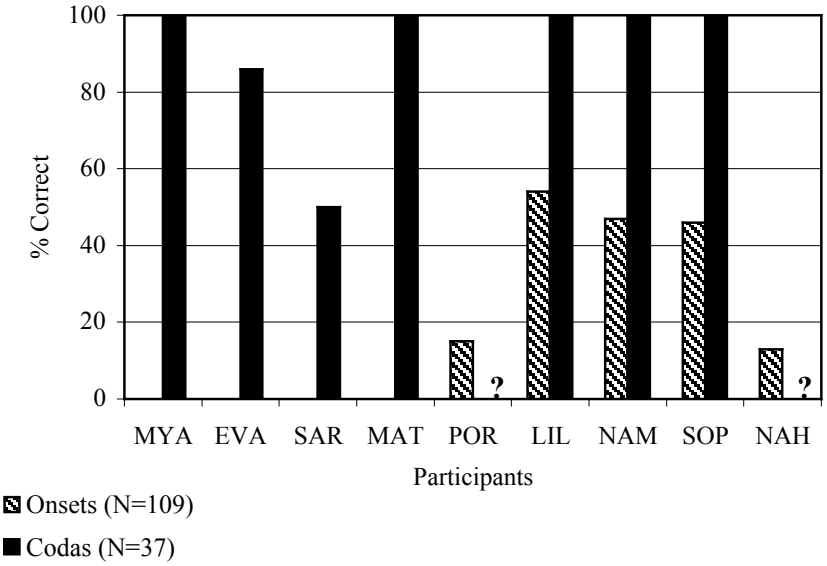

Figure 3: Percentage of /s/+nasal onset clusters and nasal+/z/ coda clusters produced target appropriately

All the target words with nasal+/z/ coda clusters were morphologically complex, so the data from the /s/+nasal and nasal+/z/ clusters do not provide us with anything new that would allow us to either support or refute a explanation that relies on differences in morphological complexity.

Both nasal+/z/ coda clusters and /s/+nasal onset clusters appear in child-directed speech with low frequency (2% and .7%, respectively). However, nasal+/z/ codas occur almost 3 times as frequently in the input as /s/+nasal onsets. Thus, once again, the coda clusters are more frequent in the input children hear, and these coda clusters are also more accurately produced.

Note that a strict frequency hypothesis would predict that both /s/+nasal clusters and nasal+/z/ clusters would be produced less accurately than the much more frequently occurring stop+/s/ coda clusters mentioned above. However, as we have seen, this prediction was not realized. This suggests that while children may be sensitive to the frequency of consonant clusters in the input, they are not tuning in to the absolute frequency of specific cluster types. Instead, it seems that children are sensitive to frequency effects at a more global level, such that the much higher frequency of coda clusters taken as a group (74%) make them easier to produce than the relatively low frequency onset clusters (26%).

3.2 Metathesis Errors

When attempting target clusters, the majority of errors made by the children in our study involved cluster simplification. Much of the previous literature on the acquisition of English clusters has focused on whether children's reduction patterns are best explained by sonority (e.g., Gnanadesikan, in press; Ohala, 1995; Pater & Barlow, 2002), headedness (Goad & Rose, 2002), or directionality, i.e., whether C1 or C2 is more likely to be preserved (Lleó & Prinz, 1996).

In our study, we were more concerned with actual cluster production itself. Interestingly, we found that 23% of children's attempted coda /s/+stop clusters resulted in metathesis (e.g., *wasp* /wɑsp/ was pronounced as [wɑps]). Six of the 9 children in our study made this type of metathesis error. No other metathesis errors were found in the study.

Why should only this particular cluster type be subject to metathesis? In a recent typological study of consonant metathesis in the world's languages Hume (2002) claims that in many cases the output of metathesis corresponds to the most common ordering of segments in a language. She also notes that metathesis sometimes results in improved acoustic/auditory cues in the output.

A change from an /s/+stop to a stop+/s/ coda sequence does not appear to be motivated on the grounds of improved perceptual salience. In stop+/s/ coda clusters there will be some stop information in the transition from the previous vowel, and possibly a release of the stop into the fricative similar to that observed in affricates. For /s/+stop clusters, there is the possibility of a stop release, but the listener will not gain any information about the stop during the previous fricative. Therefore, in terms of the perceptibility of /s/+stop and stop+/s/ clusters, there would seem to no clear winner.

One possibility is that differences in structure can account for the metathesis errors. As discussed earlier, stop+/s/ final clusters are commonly assumed to consist of a singleton coda plus appendix. In contrast, /s/+stop final clusters have been analyzed as having branching structure either at the level of the coda (Giegerich, 1992) or at the level of the segment (Fudge, 1969; Selkirk, 1982).

Frequency may be an important factor in explaining this type of metathesis. We have already seen that stop+/s/ coda clusters are extremely frequent in English child-directed speech, accounting for 22% of all cluster types. In

contrast, /s/+stop codas clusters make up only 4% of the cluster input. A possible explanation for these [wɑps] types of metathesis errors may therefore be that children are replacing a less frequent cluster type with a more frequent cluster type. Note that these metathesis errors have nothing to do with morphology – all were produced when looking at a single object (e.g., *wasp, toast, desk*).

3.3 Summary

Table 2 shows the number of children in our study who produced each of the subtypes of onset and coda clusters with greater than 70% accuracy. Coda clusters were produced more reliably than onset clusters with the exception of /s/+stop coda clusters which tended to undergo metathesis. Although these are cross-sectional data, the implication of these findings is that coda clusters are generally acquired before onset clusters.

Table 2: Number of children who produced each cluster type with greater than 70% accuracy

Onset Clusters	Coda Clusters
/s/+stop = 3	stop+/s/ = 7
/s/+nasal = 0	nasal+/z/ = 6
C+/j/ = 3	nasal+stop = 5
C+/l/ = 2	/s/+stop = 2
C+/ɹ/ = 1	
C+/w/ = 1	

4. Conclusions

In this paper, we have shown that English-speaking two-year-olds produce coda clusters more accurately than onset clusters, and by implication, coda clusters are acquired before onset clusters. We investigated several possible explanations for these findings. One explanation we considered was that coda clusters may have simpler structures, and it may be that these simpler structures are easier to produce. However, structural differences cannot account for the asymmetry we find in the production of /s/+stop onsets and stop+/s/ codas since it is generally assumed that both of these clusters consist of a singleton consonant and an appendix.

We also considered a morphological explanation of the onset/coda asymmetry. However, we showed that accuracy in cluster production is independent of morphological complexity. We found no difference in the production accuracy of clusters that were phonologically identical but varied in morphological structure. For example, production of the morphologically simple *box* /bɑks/ was just as accurate as that of the morphologically complex *ducks* /dʌks/. It is therefore unlikely that better performance on *cups* /kʌps/ than on

spoon /spun/ is due to differences in their morphological structure. The onset/coda asymmetry therefore does not appear to be morphologically conditioned.

We then showed that there was a positive correlation between accuracy of cluster production and the frequency with which clusters occur in the ambient language. In English child-directed speech, coda clusters occur 3 times more frequently than onset clusters, and the children in our study produced coda clusters with much greater accuracy then onset clusters.

Frequency may also be able to explain a similar tendency for coda clusters to be acquired before onset clusters by children acquiring German since coda clusters are more frequent than onset clusters in this language as well (Kehoe & Lleó, 2003). This study also found that Spanish-German bilinguals speaking German acquired complex codas before complex onsets. These results are somewhat surprising given that initial clusters occur in both languages whereas final clusters only occur in German. This suggests that Spanish-German bilinguals are tuning in to the frequency of clusters in German rather than combining frequencies over the two input languages.

Our findings contribute to a growing body of research showing that young children are sensitive to the statistical properties of the ambient language. This sensitivity to phonological frequency has been shown for both perception (Jusczyk, 1997; Morgan, 1996; Saffran, Aslin, & Newport, 1996) and more recently for production (Beckman & Edwards, 2000; Levelt, Schiller, & Levelt, 2000; Roark & Demuth, 2000). Although it is possible that structure, morphology, and frequency all contribute to more accurate production of coda clusters, only frequency provides a unified account of the onset/coda asymmetries found in this study.

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