Substitution Errors in the Production of Word-Initial and Word-Final Consonant Clusters

Cecilia Kirk
University of Canterbury, Christchurch, New Zealand

Purpose: This study provides a comprehensive examination of substitutions that occur at Greenlee's 3rd stage of cluster development (M. Greenlee, 1974). At this stage of cluster acquisition, children are able to produce the correct number of consonants but with 1 or more of these consonants being substituted for another.
Method: Participants were 11 typically developing children ages 1;5–2;7 (years;months) who were from monolingual English-speaking homes. Consonant clusters in both word-initial and word-final position were elicited using a picture identification task.
Results: Although previous studies have suggested that most cluster substitutions can be predicted from the errors children make on the corresponding singletons, our findings indicate that almost one third of substitutions in clusters are not predictable in this way. Furthermore, the majority of unpredictable substitutions produced by the children in this study resulted in clusters in which both consonants in the cluster shared the same place and/or manner of articulation. Thus, almost 70% of unpredictable substitutions appear to be motivated by assimilation within the cluster.
Conclusion: Ease of articulation provides the most convincing explanation for within-cluster assimilation.

KEY WORDS: consonant clusters, substitution errors, place assimilation, word-final clusters, typical phonological development

Consonant clusters are difficult for children to produce, and they are not typically mastered until after 3 years of age (Smit, Hand, Freilinger, Bernthal, & Bird, 1990). Children usually progress through a number of stages between their first attempts at consonant clusters and the final correct production. These stages in the acquisition of clusters were first formalized by Greenlee (1974). In Greenlee's earliest stage of cluster development, the entire cluster is deleted—for example, *desk* → [dɛ]—although this is fairly rare. In contrast, Greenlee's second stage of cluster development, which involves reduction to a single consonant—for example, *snake* → [neɪk]—is very common and often persists for several months or more. In Greenlee's third stage of cluster acquisition, the number of elements in the cluster is preserved but with substitution of one or more of the consonants in the cluster—for example, *frog* → [fwɑg]. Finally, children achieve full accuracy in producing clusters. Although children tend to move through a similar progression when acquiring consonant clusters, not all children pass through all these stages for each consonant cluster. Furthermore, there is usually some overlap in the various stages of cluster production such that reduction to a single consonant may be the predominant production pattern for one cluster type at the same time that a different cluster type typically undergoes substitution of one of its consonants (Ingram, 1976).

The order in which different consonant clusters are acquired has received much attention. Many of these studies focus on children's cluster production without reference to the standard adult pronunciation (e.g., Dyson, 1988; 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 (Kirk & Demuth, 2005; Levelt, Schiller, & Levelt, 2000; McLeod, van Doorn, & Reed, 1997, 2001; Smit, 1993b; Templin, 1957).

Investigation into the specific errors that children produce as they acquire clusters provides important insight into the various constraints that operate on developing grammars. Much of the previous research on error patterns in cluster production has focused on the reduction of consonant clusters to a single consonant (e.g., Gnanadesikan, 2004; Goad & Rose, 2004; Jongstra, 2003; Lleó & Prinz, 1996; Ohala, 1999; Pater & Barlow, 2003; Wyllie-Smith, McLeod, & Ball, 2006). Many studies on cluster reduction have been concerned with the role of sonority in determining which element of the cluster is preserved (e.g., Gnanadesikan, 2004; Ohala, 1999; Pater & Barlow, 2003; Wyllie-Smith et al., 2006). The sonority of a consonant depends on the degree of constriction in the vocal tract when that consonant is produced, with the ranking of consonants from the most sonorous to the least sonorous being glides, liquids, nasals, fricatives, and stops. The most common reduction pattern for onset clusters is one in which the least sonorous consonant of the adult target form is produced (Ohala, 1999).

Reduction errors in cluster production usually involve preservation of either the first or second consonant of the adult target form. However, it is also possible for a cluster to be reduced to a single consonant that is not identical to either of the consonants in the adult target cluster. Reductions of this type involve both deletion and substitution and are much less common than reduction to one of the target consonants. Relatively little work has been undertaken to explain errors that involve both deletion and substitution. One subtype of reduction with substitution involves the production of a single segment that combines phonological features from each of the two consonants in the adult cluster—for example, *spoon* /spun/ pronounced as [fun], in which the [f] preserves the continuancy of the /s/ as well as the labial place specification of the /p/. This type of reduction error is called *coalescence* and has been discussed by Chin and Dinnsen (1992) and Pater and Barlow (2003), among others.

Only a few studies have investigated errors from Greenlee's third stage of cluster development (Chin & Dinnsen, 1992; Greenlee, 1974; McLeod et al., 1997, 2002; Olmsted, 1971; Smit, 1993b). These errors are characterized by productions in which the number of elements in the cluster is preserved but one or more consonants in the cluster is substituted. Some of the studies investigating this particular error type provide a useful typology for classifying subtypes of substitutions (Chin & Dinnsen, 1992; McLeod et al., 1997; McLeod et al., 2002). These typological studies classify cluster productions according to whether the first consonant in a cluster is substituted, whether the second consonant is substituted, or whether both consonants are substituted. For example, McLeod et al.'s (2002) investigation of cluster production by typically developing 2-year-olds found that for word-final clusters, the most common substitution pattern was accurate production of the first consonant in a cluster and substitution of the second consonant. For initial clusters, a different pattern was found, with substitution of the second element of the cluster being more common for initial stop clusters and substitution of the first cluster element being more common for initial fricative clusters. Similar typologies have been proposed for children with speech impairment (Chin & Dinnsen, 1992; McLeod et al., 1997). Although these studies provide valuable information about the range and prevalence of different substitution errors, the segmental content of the child's substituted cluster is never discussed, so it is not possible to determine which phonological processes, if any, are motivating these errors. Thus, typological error analyses such as these do not allow specification of the phonological and phonetic constraints that may be driving children's production errors.

For the remainder of this section, discussion is limited to studies that have looked at the actual segments that have undergone substitution when the number of elements in the cluster is preserved. Greenlee (1974) compared the production of stop-liquid clusters by 10 children learning to speak six different languages (Czech, English, Estonian, French, Serbian, and Slovenian). She found that the substitution errors for stop-liquid clusters in which two elements were produced were surprisingly similar cross-linguistically, given that the phonetic characteristics of /r/ are very different in the six languages. Among the different types of substitution errors discussed by Greenlee are stop-weakening, substitution of [l] for /r/, consonant harmony, and gliding of /r/. Stop-weakening occurs when a stop is replaced with a fricative in agreement with the continuancy of the following liquid and is thus an assimilatory process—for example, the Czech word *kladivo* "hammer" → [xladivo]. Substitution of the liquid [l] for /r/ occurred in five different languages—for example, *bread* /brɛd/ → [blɛd]. The phonetic/phonological motivation for this particular substitution error is not clear. It may be that this substitution is caused by articulatory confusion between liquids, but if this were the case, one would expect substitutions of [r] for /l/, and none are reported in this study. Alternatively, the substitution of [l] for /r/ may occur because /r/ is not in the child's phonetic repertoire and the child attempts to match the target sound with a segment that is acoustically similar.[1]

The remaining two types of substitution errors discussed by Greenlee are regressive consonant harmony (e.g., *truck* /trʌk/, pronounced as [ɡlʌk]) and gliding of /r/ (e.g., *brown* /braʊn/, pronounced as [bwaʊn]). Both of these error types reflect substitutions that are not specific to cluster production: Consonant harmony often occurs with singletons—for example, *duck* /dʌk/ → [ɡʌk]—and it is widely reported that [w] substitutes for /r/ in singletons, at least for children learning English. Although Greenlee's study indicated that a variety of substitution processes occur, some of which are specific to cluster production and others of which are not, her study is limited by the small number of cluster types examined and by the fact that the errors are described but are not quantified.

A large-scale study by Smit (1993b) detailed the errors on word-initial consonant clusters from 1,049 English-speaking children between the ages of 2 and 9 years. One of the error types discussed by Smit involves preservation of the number of elements in the cluster but with substitution of one or more of the cluster elements. Smit claims that "virtually all the common [substitution] errors are predicted from the errors on the corresponding singletons. For example, at the same ages that children are using the gliding process for liquid singletons [Smit, 1993a], they are also using glides for clustered liquids" (Smit, 1993b, p. 943).

Olmsted (1971) presented data on cluster production in both word-initial and word-final position from 54 children aged 15 to 54 months.[2] He suggested that the errors for clusters in which one or more members of the cluster are substituted can be classified according to process (e.g., assimilation, dissimilation). Assimilation errors in cluster production occur when the erroneous consonant becomes more similar on some phonetic dimension to the adjacent consonant than was the target consonant—for example, *box* /bɑks/ produced as [bɑts] shows assimilation of place of articulation within the final cluster. On the other hand, dissimilation errors occur when the erroneous consonant becomes less similar on some phonetic dimension to the adjacent consonant—for example, *skates* /skeɪts/ produced as [ɡeɪps] shows dissimilation of place of articulation within the final cluster. In Olmsted's data there are only six substitution errors in word-initial position from a total of 85 attempted tokens and seven substitution errors in word-final position from a total of 127 attempted tokens. Olmsted identified three instances of assimilation within the cluster, one instance of dissimilation, and two instances of metathesis, with the phonological process for the remaining seven responses being analyzed as "impossible to identify" (Olmsted, 1971, p. 222). As Olmsted himself admits, these data are too sparse to permit conclusive findings as to which substitution process is the most widespread in cluster acquisition.

Assimilatory processes are widespread in early phonological development. Recent research reports a preference for place agreement at the level of the word in children's earliest utterances (Fikkert & Levelt, 2002). In this study, longitudinal data from 5 Dutch children between the ages of 1 and 3 years were analyzed, and it was found that the place of articulation patterns in these children's earliest words were restricted to homorganic consonants and vowels—for example, *boek* "book" → [bup], in which the labial vowel /u/ is surrounded by two labial consonants. Thus, at this developmental stage, the child can only produce one place specification for each word. Children usually move through this stage relatively quickly, but it may be that a similar restriction on place reemerges when more complex syllable structures are beginning to be acquired. At this later stage in development, there would no longer be a requirement that all the segments in a word be produced at a single place of articulation, and instead there would be a preference for complex onsets and complex codas that share a single place of articulation.

The purpose of this paper is to provide a close examination of substitutions that occur at Greenlee's third stage of cluster development. At this stage of cluster acquisition, children are able to produce the correct number of consonants but with one or more of these consonants being substituted for another. We investigated this particular type of substitution pattern in both the word-initial and word-final position as produced by typically developing 1- and 2-year-olds. Although in this study we have restricted our attention to clusters in which the correct number of consonants is produced, it is important to acknowledge that overlap is likely to occur between the various stages of cluster acquisition. That is, the children in our study will likely produce some clusters correctly at the same time that they are substituting or reducing other clusters. Furthermore, as discussed earlier, clusters can be produced as a singleton that is different from either consonant in the target cluster. However, clusters that involve both substitution and reduction errors are not the focus of this article. Instead, we restrict our attention to substitution errors in clusters in which the number of consonants in the cluster has been preserved.

First, we evaluate whether or not the vast majority of substitution errors can be predicted from errors on the corresponding singletons, as has been suggested by Smit (1993b). This is a rather different interpretation of cluster

[1]Thanks to an anonymous reviewer for this alternative explanation.
[2]Olmsted (1971) also elicited clusters in utterance-medial position. However, in the majority of instances, the consonants constituting these clusters were separated by a syllable boundary. These heterosyllabic clusters have a very different prosodic structure from the (tautosyllabic) clusters in utterance-initial and utterance-final position. For this reason, we do not discuss Olmsted's analysis of targets containing consonantal sequences in utterance-medial position.

substitutions than that of Olmsted, who classifies substitution errors according to the influence of neighboring sounds (Olmsted, 1971, p. 222). Olmsted explains substitutions in cluster production as being due to interactions between adjacent segments, whereas Smit explains these same errors as being largely due to the way that individual segments in a cluster are produced as singletons. If we find that substitution errors cannot always be predicted from singletons, we will investigate the systematicity of these unpredictable substitutions. We then test the hypothesis that many unpredictable substitution errors are motivated by assimilation processes within the cluster—in particular, assimilation of place. In the final section of the article, we explore the clinical implications of recognizing this type of error pattern as part of typical linguistic development.

Method

Participants

The participants were eleven 1- and 2-year-olds (7 girls, 4 boys) from monolingual English-speaking homes in Rhode Island, USA. Their mean age was 2;1 (range = 1;5–2;7). All participants had their hearing screened as newborns, and there were no parental concerns as to the speech, language, or hearing development of any of the participants. Nine of the participants were recruited from a local childcare center, where a letter was sent to parents inviting their child to participate in the study if he or she was between 18 months and 3 years, had normal hearing, and had no identified disorders. The remaining 2 participants were recruited from a longitudinal study of children with typical language development.

Materials

The test items were picturable English nouns and color adjectives with a biconsonantal cluster in word-initial position and/or word-final position. All consonant clusters were in stressed syllables. Because we wished to compare the pronunciation of the same consonants in clusters and as singletons, picturable monosyllabic nouns with singleton consonants in both codas and onsets also were included. A complete list of the test items is provided in the Appendix. 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 the Appendix, where they are marked by an asterisk. Most productions by the participants in the study were single words. However, if multiword utterances were produced, only word-initial clusters that were also utterance-initial and word-final clusters that were also utterance-final were analyzed. This was to eliminate instances in which 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 consonant+glide, word-initial obstruent+/l/, word-initial obstruent+/r/, word-final nasal+/z/, word-final stop+/s,z/, word-final nasal+stop, and word-final /s/+stop. Almost all of the test items with word-final nasal+/z/ and word-final stop+/s,z/ clusters were bimorphemic, which introduces potential confounds with language skills. However, as these clusters are among the first to be acquired by typically developing children (Kirk & Demuth, 2005), it was decided to include them as target clusters.

Word-final clusters involving liquids were not targeted. The dialect of English spoken by local Rhode Islanders has no /r/ in postvocalic position. Furthermore, 2-year-olds have difficulty producing word-final liquid+consonant clusters accurately; they typically glide postvocalic liquids, both when the liquid is a singleton and when it is the first element of a word-final cluster (Ohala, 1999). Because of the difficulty of reliably determining the presence versus absence of a glide after a vowel, 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 because, with the exception of *gloves,* nouns containing these clusters are unfamiliar to 2-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 when possible; otherwise, imitations were encouraged. Each child's speech was digitally recorded with a SONY ECM-MS907 stereo condenser microphone held within 16 in. 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. This allowed us to calculate the number of clusters that were produced correctly relative to the total number of attempted clusters. Each session lasted 20–40 min and took place either in the child's home or in a quiet room at his or her childcare center.

Data Transcription

All data were transcribed offline 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). All transcribers were experienced in transcribing the speech of young children.

Data Analysis

No standardized language assessment was administered to the participants. Given that most of the test items with word-final nasal+/z/ and word-final stop+/s,z/ clusters included the plural marker, this introduces a possible confound concerning interactions between grammatical morpheme development and the acquisition of consonant clusters. As pointed out by Tyler, Lewis, Haskill, and Tolbert (2002), if a child does not produce consonant singletons or consonant clusters at the end of words, it is unlikely he or she will be able to accurately produce grammatical morphemes. It is also possible that a child may be able to produce the relevant word-final consonant clusters but has not yet acquired grammatical morphemes.

To investigate whether either of these possibilities held for the participants in our study, we carried out the following two analyses. First, accuracy on plural target words was calculated for each child. To ensure that we did not underestimate plural use, we counted as accurate consonant substitutions that could be predicted from the child's use of singleton consonants. For example, *cups* produced as [kʌpʃ] was counted as accurate production of the final cluster when that child also produced *bus* as [bʌʃ]. Averaging over a total of 300 tokens of plural target words, participants produced word-final consonant clusters with 78% accuracy (range = 66%–100%). We also compared performance on word-final monomorphemic clusters with that of word-final bimorphemic clusters. Accuracy on bimorphemic stop+/s,z/ and nasal+/z/ clusters was 78% (234 of 300), whereas the combined accuracy on monomorphemic stop+/s/, nasal+stop, and /s/+stop clusters was 49% (188 of 385). This lower accuracy on the monomorphemic clusters was due to poor performance on /s/+stop clusters, which were produced with 31% (29 of 93) accuracy, and on nasal+stop clusters, which were produced with 50% (122 of 246) accuracy. Monomorphemic stop+/s/ clusters, on the other hand, were produced with 80% (37 of 46) accuracy, which was very similar to performance on the bimorphemic stop+/s,z/ and nasal+/z/ clusters. Thus, it is the segmental content of a cluster rather than its grammatical status that appears to determine production accuracy. These results suggest that it is unlikely that any of the participants in our study had impaired plural morphology. In the analyses that follow, we collapse bimorphemic and monomorphemic clusters into a single category.

A total of 1,935 word tokens with biconsonantal clusters in word-initial or word-final position were analyzed. Each participant contributed between 69 and 87 word types (*M* = 77) and between 126 and 222 word tokens (*M* = 176 tokens) to the analysis. Table 1 gives a breakdown of the number of word types and word tokens by position within the word (word-initial, word-final) for each participant. Most of the test items were produced multiple times by each participant. The mean number of repetitions produced for each word type was calculated for each participant. Averaging over all participants, the range was 1.9–2.7 tokens per type (*M* = 2.3 tokens). Participants frequently produced different phonetic forms for each of the test items. This type of variability is common in the early stages of phonological development (e.g., Jongstra, 2003; Vogel-Sosa & Stoel-Gammon, 2006). The results discussed in the following section are presented as proportions of the total number of tokens produced; thus, all repetitions of a test item contributed equally to the analysis.

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

When a child's production of the target cluster matched the standard adult pronunciation, it was classified as being produced correctly; otherwise, it was classified as an error. Table 2 gives examples of the types of productions that were classified as errors. Note that errors classified as reduction to a singleton include some coalescence 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 because a reliable voicing distinction in codas is late to develop

Table 1. Word types and word tokens by word position for each participant.

Participant	Age (years;months)	Word-initial clusters		Word-final clusters	
		Type	Token	Type	Token
SOP	2;2	55	129	25	64
LIL	1;10	53	128	28	67
NAH	2;7	46	86	25	51
NAI	1;5	47	62	31	64
NAM	2;2	47	115	27	59
LIY	1;9	47	106	31	75
MAT	2;5	56	142	26	69
POR	2;3	47	111	22	42
EVA	1;7	56	137	31	85
MYA	2;3	47	126	27	71
SAR	2;2	51	108	21	38
M	2;1	50	114	27	62
Range	1;5–2;7	47–56	62–142	21–31	38–85

Table 2. Examples of productions classified as errors.

Error type	Target word	Child's response
Reduction	glove /glʌv/	[ˈgʌv]
Predictable substitution[a]	spoon /spun/	[ˈʃpun]
Unpredictable substitution[b]	blocks /blɑks/	[ˈblɑts]
Deletion	desk /dɛsk/	[ˈdɛ]
Metathesis	toast /toʊst/	[ˈtoʊts]
Consonant insertion	wasp /wɑsp/	[ˈwɑpst]
Non-schwa epenthesis	blue /blu/	[ˈbʌlu]

[a]These substitutions are predictable from the child's production of singletons. For example, if a child realized *sun* as [ʃʌn] and pronounced *spoon* as [ʃpun], then this was analyzed as a predictable substitution error.
[b]These substitutions are not predictable from the child's production of singletons. For example, if a child pronounced *block* as [blɑk], but *blocks* as [blɑts], then this was analyzed as an unpredictable substitution error.

(Stoel-Gammon & Buder, 1999). For example, if *pigs* /pɪgz/ was pronounced as [pɪks], the child was considered to have produced this cluster correctly.

Following the influential work by Smit et al. (1990) on speech sound acquisition and the important work by Smit (1993b) on word-initial consonant clusters, productions in which schwa was inserted between the first and second element of a consonant cluster were coded as acceptable productions. Smit has argued that schwa epenthesis in a cluster should not be classified as an error because it can occur in adult colloquial speech, for example when speaking emphatically. Furthermore, in the data presented in the current study, schwa epenthesis only occurred in word-initial consonant+sonorant clusters and this is compatible with the idea that schwa insertion represents a lengthened transition into the sonorant rather than true vowel insertion. On the other hand, productions in which a child epenthesized a vowel other than schwa (i.e., the vowel was stressed) were coded as errors.

Substitutions were classified as being either predictable from the way a child produced the relevant singletons or unpredictable from the child's singleton productions. For example, if a child realized *sun* as [ʃʌn] and pronounced *spoon* as [ʃpun], this was analyzed as a predictable substitution. On the other hand, if a child pronounced *block* as [blɑk] but *blocks* as [blɑts], this was analyzed as an unpredictable substitution. Predictable substitutions have not been included in the analysis that follows. For example, if a child produces word-initial /l/ as [w] in singletons—for example, *lamps* → [wɛps]—we do not analyze /l/ → [w] in clusters, such as *slide* /slaɪd/ → [fwaɪd], as a change in place (from coronal to labial) and manner (from liquid to glide). However, for this particular example, the substitution of [f] for /s/ would be analyzed, as this change cannot be predicted from the child's production of the relevant singleton—that is, the child does not produce *sun* as [fʌn].

For the purposes of place classification, three broad place categories were used: labial, coronal, and velar. We followed Pater and Barlow (2003) and Gnanadesikan (2004) in assuming that the American English consonant /r/ in onsets is underlyingly labial, at least in children's early phonological development. This assumption seems reasonable given that in American English, /r/ is produced with lip rounding as a secondary articulation, and this may explain why children frequently realize onset /r/ as [w] in their early speech. Further evidence in support of this assumption is provided by examples of coalescence between a nonlabial obstruent and /r/, which yields a labial obstruent. For example, one child from the current study produced [fi] for the target word *tree* /tri/, and [feɪ] for the target word *train* /treɪn/. See Pater and Barlow (2003, p. 510) for additional examples of this type of coalescence. These productions are difficult to explain unless we assume that /r/ is underlyingly labial. Similarly, /l/ is often produced as [w], and examples in our data such as *slide* /slaɪd/ → [faɪd] suggest that /l/ has a labial place specification, at least for those children who produce it as [w]. In what follows, we assume /r/ and /l/ to be labial if the child produced these consonants as [w] in singleton contexts. The labial place classification also included the bilabials /p, b, m/, the labio-velar /w/, and the labio-dentals /f, v/. The coronal place classification included the alveolars /t, d, n, s, z, (l, r)/, and palatals /j, ʃ, tʃ, dʒ/. The velar place classification included /k, g, ŋ/. None of the test items included interdentals or the voiced palatal fricative /ʒ/.

Results

The raw numbers for each of the different response types by participant are shown in Table 3. The total number of clusters correctly produced was 34% (652 of 1,935). Reduction of a cluster to a singleton was the most common error, accounting for 43% (841 of 1,935) of all responses. Predictable substitutions were the second most common error type, accounting for 15% (289 of 1,935) of total responses. Unpredictable substitutions were the third most common error type, accounting for 6% (118 of 1,935) of total responses. Of the total substitution errors, substitutions that could be predicted from the production of the corresponding singletons made up 71% (289 of 407) of all substitutions combined, whereas unpredictable substitution errors made up 29% (118 of 407) of all substitutions. Thus, almost one third of cluster substitutions could not be predicted from the production of singletons.

The remainder of this section is devoted to examining the precise nature of unpredictable substitution errors

Table 3. Response types by participant as raw numbers.

Participant	Reduction	Correct	Predictable substitution	Unpredictable substitution	Deletion	Metathesis	Consonant insertion	Non-schwa epenthesis	Total by participant
SOP	41	114	22	11	1	3	1	0	193
LIL	40	110	27	15	0	1	0	2	195
NAH	15	72	41	4	0	5	0	0	137
NAI	30	60	33	2	1	0	0	0	126
NAM	50	74	34	15	1	0	0	0	174
LIY	51	54	42	32	0	0	1	1	181
MAT	144	55	0	7	0	4	0	1	211
POR	95	34	19	3	2	0	0	0	153
EVA	130	42	30	12	8	1	0	0	223
MYA	142	27	14	12	1	0	0	0	196
SAR	103	10	27	5	0	1	0	0	146
Total by response type	841	652	289	118	14	15	2	4	1,935
Percentage of grand total	43	34	15	6	<1	<1	<1	<1	

with the aim of testing the hypothesis that there is a preference for clusters that share the same phonological features in terms of place of articulation and/or manner of articulation. In the data presented here, unpredictable substitutions generally occurred for only one of the two consonants in a cluster. The two exceptions occurred in onset clusters and were *smiley* /smaɪli/ → [bwaɪji] and *fruits* /fruts/ → [sputs]. For these items, each consonant substitution contributed separately to the analysis—for example, for *smiley*, /s/ → [b] was analyzed as a place and manner change, and /m/ → [w] was analyzed as a manner change.

Substitution Errors by Position

The number of unpredictable substitutions in onset clusters as a proportion of all targets with onset clusters was 6% (70 of 1,250), whereas in coda clusters, the number of unpredictable substitutions as a proportion of all targets with coda clusters was 7% (48 of 685). This difference was not significant, $\chi^2(1, N = 1{,}935) = 1.53, p = .22$. This contrasts with predictable substitutions, which were significantly more frequent in onsets than in codas: 17% (210 of 1,250) versus 12% (79 of 685), $\chi^2(1, N = 1{,}935) = 9.66, p = .002$. The higher proportion of predictable substitutions in onsets than in codas was largely due to the high prevalence of [w] substitutions for /r/ in stop+liquid clusters, with 10 of the 11 participants making this substitution to a lesser or greater degree.

Place Preferences by Position

In developing phonological systems, there is often a stage during which there is a preference for labial singleton consonants in syllable-onset position and singleton velars in syllable-coda position (Ingram, 1974). That is, singleton labials are acquired earlier and are produced more accurately in syllable-initial position, whereas in syllable-final position, singleton velars are acquired earlier and are produced more accurately. A preference for labials has also been noted in the reduction patterns for onset clusters by Gnanadesikan (2004) and Pater and Barlow (2003), who discuss examples of coalescence in which the feature [labial] dominates—for example, *tree* /tri/ → [pi].

We investigated whether preferences for labials in onsets and velars in codas hold with cluster substitution errors. We found that for target onset clusters consisting of a labial consonant[3] and either a coronal or velar consonant, the labial place specification dominated—for example, *green* → [bwin], *swing* → [fwɪŋ]. However, if the target onset cluster consisted of a coronal and a velar consonant, then the coronal consonant dominated—for example, *cube* → [tjup], *skunk* → [stʌk]. In codas, a rather different pattern emerged. Target clusters consisting of a coronal and velar (in either order) or a coronal and labial (in either order) were produced as two coronals—for example, *box* /bɑks/ → [bɑts], *desk* /dɛsk/ → [dɛts], *grapes* /greɪps/ → [greɪts], *wasp* /wɑsp/ → [wɑst]. Although singleton velar codas are generally produced more accurately than singleton codas at other places of articulation, we found that this did not hold for velars in coda clusters. A possible explanation for why coronals dominate in complex codas is that coronals are the unmarked place of articulation (Paradis & Prunet, 1991), with many languages restricting codas to coronal consonants. It is worth noting that in English, all word-final consonant clusters include at least one coronal consonant, with the exception of the homorganic nasal+stop clusters /mp/ and /ŋk/.

[3]Note that we analyzed /r/ and /l/ as labial if the child produced these consonants as [w] in singleton contexts.

We now discuss the various unpredictable substitution errors according to whether the change affected place of articulation only, manner of articulation only, or both place and manner of articulation.

Substitution Errors That Involve a Change in Place of Articulation Only

Of the total unpredictable substitution errors, 54% (64 of 118) involved clusters in which the consonants in the target cluster did not share place of articulation (different-place clusters), and they were substituted by clusters that shared place features (same-place clusters)—for example, *green* /grin/ → [bwin]. Of these place assimilations, it is possible that 16 substitutions were due to assimilation across a vowel to a preceding or following consonant rather than to assimilation within a cluster—for example, *ducks* /dʌks / → [dʌts], in which perhaps the / k / has assimilated to the coronal place of the initial consonant rather than to that of the (coronal) final consonant. However, this alternative seems unlikely, given that harmony across the vowel is absent when there is no cluster—for example, *duck* /dʌk/ → [dʌk]. Furthermore, children who produced *ducks* /dʌks/ as [dʌts] also produced the substitution of [ts] for /ks/ in words in which there was no trigger consonant for harmony outside the cluster—for example, *box* /bɑks/ → [bɑts].

A closer look at these substitution errors in which a cluster changed from a different-place cluster to a same-place cluster shows that in word-initial position, most changes resulted in labial clusters (58% [18 of 31])—for example, *slide* /slaɪd/ → [fwaɪd]—but there were also a substantial number of changes resulting in coronal clusters (42% [13 of 31])—for example, *skunk* /skʌŋk/ → [stʌk] and *cube* /kjub/ → [tjup]. In word-final position, there was a very strong preference for coronal clusters (97% [32 of 33])—for example, *wasp* /wɑsp/ → [wɑst] and *box* /bɑks/ → [bɑts].

On the other hand, there were relatively few unpredictable substitution errors in which same-place target clusters were replaced by different-place clusters (6% [7 of 118])—for example, *flag* /flæg/ → [twæk] (where /l/ is realized as [w] in singleton onsets by this child). Other errors involving place substitution were those in which same-place target clusters were replaced by other same-place clusters (2% [2 of 118])—for example, *lamp* /læmp/ → [lænt]. There were also errors in which different-place clusters were replaced by other different-place clusters (9% [11 of 118])—for example, *eggs* /ɛgz/ → [ɛbz].

Substitution Errors That Involve a Change in Manner of Articulation Only

Unpredictable substitution errors that involved only a change in manner were much less frequent than those that involved only a change in place. Of the total unpredictable substitutions, only 2.5% (3 of 118) involved a change from clusters with different manner features to clusters that share the same manner features—for example, *ducks* /dʌks/ → [dʌkt]. A further 6.5% (8 of 118) of substitutions occurred in clusters consisting of a fricative and a nasal. In these cases, nasality was lost, and the resulting cluster was produced entirely with an oral gesture—for example, *snake* /sneɪk/ → [steɪk], *smiley* /smaɪli/ → [swaɪji]. A further 3.5% (4 of 118) of substitutions involved the two members of the cluster becoming more similar in manner through lenition of a stop—for example, *present* /prɛzənt/ → [fwɛzət]. Thus, 12.5% (14 of 118) of substitution errors could be considered to be motivated by various assimilatory processes that involved changes in manner.

On the other hand, only 2.5% (3 of 118) of substitutions involved the two members of the cluster becoming less similar in manner through fortition of fricatives to stops—for example, *froggy* /frɑgi/ → [pwagi] or *slided* /slaɪdəd/ → [twaɪdəd]. Although stopping is a frequent process in the acquisition of singleton fricatives and affricates (Ingram, 1976), neither of the children who stopped fricatives in clusters stopped the relevant consonants when produced as singletons, although it is possible they did so at some earlier point in their development. These instances of fortition may reflect a preference for a large sonority difference between the two members of a cluster, which is the unmarked cluster type (Gierut, 1999). A further 3.5% (4 of 118) of substitutions involved liquid confusions—for example, *clown* /klaʊn/ → [kraʊn]—or liquid-glide confusions—for example, *swing* /swɪŋ/ → [ʃrɪŋ].

Substitution Errors That Involve a Change in Both Place and Manner of Articulation

Only a small number of unpredictable substitution errors involved changes in both place and manner (8.5% [10 of 118]). Most of these involved place assimilation, some with lenition (2.5% [3 of 118])—for example, *Tweety* /twiti/ → [fwi]—and others with fortition (2.5% [3 of 118])—for example, *sweater* /swɛtə/ → [pwɛə]. The remaining errors showed dissimilation in both place and manner (3.5% [4 of 118])—for example, *queen* /kwin/ → [knin].[4]

Substitution Errors That Were Difficult to Categorize

A further 4% (5 of 118) of unpredictable substitutions were not analyzed under any of the preceding categories. One child (MYA) produced *star* /sta/ as [tsa] and *smoke*

[4]Although the substitution of [kn] for /kw/ does not involve assimilation within the word-initial cluster, this substitution may be the result of assimilation to the word-final nasal.

/smoʊk/ as [tsoʊk]. For these items, there is no way of deciding whether a metathesized consonant cluster is being produced (with coronal substitution of the nasal stop in *smoke*), or whether the /s/ is being prestopped, which would be analyzed as cluster reduction. MYA also produced *skates* /skeɪts/ as [tʃeɪts]. This production could be analyzed as reduction to an affricate. Alternatively, as with the two examples discussed above, this production could be analyzed as metathesis with palatalization of the initial /s/ and substitution of [t] for /k/. Relevant to this alternative analysis is the fact that MYA sometimes produced word-initial singleton /s/ as [ʃ].

A different child (LIY) produced *cream* /krim/ → [pwim]/[pim] and *cube* /kjub/ → [pwub]. One possible analysis of these productions is to code them as place assimilation within the consonant cluster. However, because LIY also produced *comb* /koʊm/ → [pum] and *cups* /kʌps/ → [pʌps], a process of regressive labial assimilation across vowels may be active in LIY's grammar. Therefore, it is also possible to analyze the substitution errors in LIY's production of the consonant clusters in *cream* and *cube* as being due to assimilation across the vowel from the word-final labial consonant. Because we cannot be sure which of these two alternatives is the correct one, we have adopted a conservative approach and have analyzed these errors as difficult to categorize.

Summary of Results

A summary of the error types for unpredictable substitutions is presented in Table 4. We have argued that the vast majority of these errors were motivated by assimilation within the cluster (69%), with place assimilation accounting for the majority of the assimilation errors. Relatively few unpredictable substitutions were caused by dissimilation within the cluster (11%). The remaining unpredictable substitution errors (20%) appear to have been motivated by neither assimilatory nor dissimilatory processes.

Discussion

This study provides a detailed investigation of substitutions that occur at the stage of cluster acquisition when children are able to produce the correct number of consonants but with one or more of these consonants being substituted for another. The results of this study show overlap between Greenlee's (1974) stages of cluster development, with participants producing substitutions in clusters at the same time that they are reducing clusters to singletons and producing clusters correctly. Averaging the responses of all participants in the study, clusters were correctly produced 34% of the time. Cluster reduction was the most common error (43%), with substitutions (predictable and unpredictable combined) the second most common error type (21%). The following text summarizes the important findings of the study and offers an explanation of the data. The clinical implications of our findings are also discussed.

Table 4. Summary of error types for unpredictable substitutions as percentages.

Error type	Place	Manner	Place and manner	Difficult to classify	Total
Assimilation	54	12.5	2.5		69
Dissimilation	6	2.5	2.5		11
Other processes	9	3.5	3.5	4	20
Total	69	18.5	8.5	4	100

The first important finding of the study is that almost one third of cluster substitutions (in which the number of consonants is preserved) cannot be predicted from the production of the corresponding singletons. The relatively large number of these errors suggests that they are an important error type in the developmental progression towards accurate cluster production. This subtype of substitution error has not been studied by previous researchers, with typological descriptions of cluster production (e.g., Chin & Dinnsen, 1992; McLeod et al., 2002) having overlooked the importance of the segmental content of substituted clusters.

The second important finding of the study is that the majority of unpredictable substitution errors resulted in consonant clusters in which both members of the cluster agreed in place and/or manner of articulation. Thus, almost 70% of unpredictable substitutions appear to have been motivated by assimilation within the cluster. Assimilatory processes are widespread in the speech of young, typically developing children. One of the most common assimilatory processes found in children's earliest words is place assimilation. For example, *duck* /dʌk/ → [gʌk], in which the initial coronal takes on the place of articulation of the final velar. Assimilation of manner also occurs in children's early speech—for example, *lamb* /læm/ → [næm], in which the initial liquid takes on the manner of articulation of the final nasal. Although both place assimilation and manner assimilation have been widely discussed in the literature on child phonology (e.g., Bortolini & Leonard, 1991; Cruttenden, 1978; Stoel-Gammon & Stemberger, 1994), assimilation within clusters has received little attention.

There are several possible explanations for assimilation errors in children's early speech. One explanation for these errors is based on perceptual factors. According to this view, children make assimilation errors in their production of consonant clusters because they misperceive one or more consonants in the target cluster. However, it is very difficult to assess whether children's ability to perceive consonant clusters is equivalent to that of adults. Although children's auditory perceptual systems are reported to undergo developmental changes (Elfenbein, Small, & Davis, 1993), no studies to date have shown that children's cluster-perceiving mechanisms are deficient.

A second explanation for children's assimilation errors is based on the nature of underlying linguistic representations. One might argue that clusters that have undergone assimilation of place and/or manner are also simpler in terms of linguistic representation, as only a single place or manner specification is required for two timing slots. However, coalescence errors in cluster production suggest that children's underlying representations of clusters are adult-like. Coalescence occurs when a cluster is reduced to a single consonant that has phonological features of both elements of the target cluster—for example, *spoon* /spun/ → [fun]. It has been argued that to produce a coalesced consonant, the child must have access to the underlying form, which is fully specified as to place and manner of articulation (Chin & Dinnsen, 1992). Therefore, even though children produce clusters in which both consonants share the same place or manner specification, it seems unlikely that children store these forms in their mental lexicons in this way.

The third explanation of assimilation errors in children's early speech is based on ease of production. According to this view, assimilation involves motoric simplification in moving from the articulatory position required for one segment to the position required for the next (Browman & Goldstein, 1992). Two adjacent consonants produced at the same place or manner of articulation require less complex motor programming and control. For example, if two adjacent consonants are articulated at the same place in the vocal tract, the same lingual and/or labial gesture can be used for both consonants. Similarly, if two adjacent consonants are produced with the same degree of stricture in the vocal tract, the speaker does not have to make rapid adjustments to the manner of articulation. This production-based account appears to offer the most convincing explanation for the type of substitution errors discussed in the current paper. Smit (1993b) pointed to two additional error types that occur in the production of consonant clusters that suggest young children find clusters motorically difficult. She argued that schwa epenthesis and nasal emission of /s/ in /s/+nasal clusters are compatible with articulatory difficulties.

Assimilation is just one of a variety of phonological processes that involve simplification of the articulatory target. Simplified articulatory productions are widespread in early phonological development. The reduction of a consonant cluster to a singleton is one example of motoric simplification found in children's earliest productions. Other processes motivated by ease of articulation include deletion of word-final consonants and deletion of unstressed syllables. Thus, assimilation within a cluster is one of a number of articulatory simplifications that occur in children's early speech.

Individual variation in the production of clusters has been noted by numerous researchers (e.g., Dyson & Paden, 1983; Jongstra, 2003; Watson & Scukanec, 1997). When a child attempts to pronounce a cluster in a particular word, he or she may produce a variety of different error types. In the current study, we see instances of both predictable and unpredictable substitution errors co-occurring with the correct production. For example, participant SAR produced *box* /bɑks/ as [bɑtθ], [bɑkθ], and [bɑks]. Phonological development is a gradual process with a period of variable production often occurring before mastery of a particular phonological structure is attained (Stoel-Gammon & Dunn, 1985). A detailed study of individual variation in the production of co-occurring error types is likely to improve our understanding of the acquisition of consonant clusters. Of interest are the types of errors that co-occur and how the relative frequency of these errors changes over time. However, a discussion of this sort is clearly outside the scope of the current study and remains a topic for further research.

The results reported in this article have important clinical implications. We have shown that substitutions in clusters that are not predictable from singletons occur much more frequently than previously thought. Recognizing that these unpredictable substitution errors occur among typically developing children helps to establish the parameters of typical development. This information becomes important when assessing children with phonological difficulties, as it allows instances of impairment to be either identified or ruled out.

We have argued that difficulties in producing two adjacent consonants with different places of articulation appear to be responsible for a substantial number of unpredictable substitution errors. Thus, clusters consisting of consonants that do not share the same place of articulation appear to be more difficult to produce than clusters in which consonants share the same place of articulation. Understanding the underlying cause of production errors allows clinicians to make treatment decisions based on this information. Further research is required to determine whether children with speech sound disorders produce the same type and frequency of unpredictable substitution errors as typically developing children.

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Contact author: Cecilia Kirk, Department of Communication Disorders, College of Science, University of Canterbury, Private Bag 4800, Christchurch 8020, New Zealand. E-mail: cecilia.kirk@canterbury.ac.nz.

Appendix (p. 1 of 2). Experimental materials by cluster type.

Word-initial clusters

/s/+stop	/s/+nasal	obstruent+/l/	obstruent+/r/	consonant+glide
spoon	smile	plate	prize*	sweater
spot*	smoke	plane	pretty*	swing
spider	smash*	play*	present	beauty
Spencer*	smiley	please*	prickly*	cube
stay*	smacks*	plum*	bread	mule
stick	snake	plant	bridge	Tweety
stairs	snail	playground*	brush	queen
star	snow*	playing*	train	
sting*	snacks*	black	truck	
stop*	snowman	blue	tree	
stuck*		block	tractor*	
stuff*		blocks	drum	
steam*		blueberries*	draw*	
steps		blanket*	dress*	
stamp		(roller)blades*	drinking*	
stamper*		clock	drums	
sticker*		click*	crocodile	
stinky*		clack*	crayons*	
scarf		clown	crab	
school		cloud*	Crusty*	
skirt		clean*	green	
skates		glasses	grapes	
skunk		gloves	frog	
Scooby*		flag	froggy	
		flip*	fruits*	
		flower		
		flowers		
		slide		
		sleep*		
		sleeping*		
		slippers		
		slipped*		
		slided*		

Word-final clusters

stop+/s/	nasal+/z/	nasal+stop	/s/+stop
cups	drums	lamp	wasp
grapes	beans	jump*	toast
boots	pens*	dump*	nest
nuts*	things*	stamp	fast*
cats*	wings*	tent	desk
lots*	swings*	paint	
fruits*	balloons*	mint*	
shirts*		pink	
box		ink*	
ducks		drink*	
socks*		skunk	
chicks*		hand	
fox*		sand	
birds*		end*	
toads*			
weeds*			
seeds			
pigs			
eggs			
bugs*			

Appendix (p. 2 of 2). Experimental materials by cluster type.

Singletons	
Onsets	**Codas**
pig	cup
bus	bib
top	hat
dog	bed
cake	cake
girl	pig
sun	bus
fish	knife
moon	comb
nose	sun
shoe	fish
light	swing
red	
web	
yogurt	

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