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Production Constraints on Utterance-Final Consonant Characteristics in Babbling

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Abstract

In order to evaluate hypotheses regarding production constraints on final consonants in babbling, 721 utterance-final consonants produced by 6 infants in consonant-vowel-consonant (CVC) syllables were examined and compared with the preceding consonant in the CVC. Consistent with earlier studies, major patterns were observed for each of the three main consonantal properties – place and manner of articulation and voicing. These patterns included a strong tendency for final consonants to repeat the place of articulation of nonfinal consonants and a tendency for relatively more fricative, nasal and voiceless consonants to occur in final position than in nonfinal position. The high frequency with which final consonants shared place of articulation with the preceding consonant was considered to reflect 'frame dominance' or the tendency of a relatively constant mandibular cycle (the frame) to determine the structure of utterances with very little contribution from other active articulators. The manner and voicing effects were attributed to an overall terminal energy decrease in the vocal production system.

Introduction

Babbling is characterized by the rhythmic alternation of consonants and vowels and is perceived as having a syllabic pattern. Thus, babbling represents the infant's first speech-like vocalizations [Oller, 1980; Stark, 1980]. An understanding of babbling is important for understanding how speech is acquired. The sound patterns of the first words are highly similar to those of babbling in certain major respects, namely, in the favoring of the consonant-vowel (CV) syllable structure and in the limited repertoire of consonants and vowels [e.g., Oller et al., 1976; Vihman et al., 1985; MacNeilage and Davis, 1990a]. The speech-like structure of babbling and its similarity to early speech make the study of sound patterns in babbling fundamental to phonetics.

Babbling patterns tend to be similar across language environments [Locke, 1983; Coberly, 1985]. For instance, infant consonant repertoires are dominated by stops and nasals articulated in the anterior portion of the vocal tract. Coronal stops tend to prevail over labials. Fricatives, affricates, liquids, and dorsal consonants are disfavored.

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Even though other sounds are often as frequent in the input as the favored sounds, these babbling patterns tend to be universal, which suggests that babbling preferences are primarily determined by production factors [Locke, 1983; Menn, 1983; Oller and MacNeilage, 1983; MacNeilage and Davis, 1993]. For example, the universal preference for stop and nasal consonants over fricatives, affricates, and liquids is perhaps best explained in terms of the greater motor control necessary to execute the latter [Kent, 1992].

Another striking characteristic of babbling is that some of the sound patterns favored in babbling are also favored across languages. This characteristic might indicate that the constraints which define babbling patterns have also helped to define certain sound patterns that occur across languages. One of the most notable patterns that occurs both in babbling and across languages is a strong preference for CV syllables over syllables with final consonants [see Bell and Hooper, 1978, for cross-language information]. The fact that final consonants in babbling are scarce, even when a language environment like English provides many exemplars of syllables with final consonants, suggests that the constraints on final consonants in babbling may be associated with the vocal production system. The disfavored status of final consonants relative to initial consonants also suggests that syllable position has an effect on consonantal production, which indicates that initial and final consonants might belong to different production categories in babbling and across languages. So far in studies on infant babbling, consonantal patterns have not been considered with respect to these different syllabic positions. The present study is an attempt to systematically explore the characteristics of consonants which occur in final position by comparing final consonant characteristics with initial consonant characteristics in monosyllabic and utterance-final closed (CVC) syllables of babbling.

One major motivation for this study is to determine the extent to which final consonant characteristics are consistent with an emerging principle of 'frame dominance' [Davis and MacNeilage, 1995] applicable to babbling and early words. According to this principle, 'frames', produced by the regular close-open cycles of the mandible, are considered to serve as the vehicle within which 'content' elements – independently controlled consonant and vowel segments – eventually develop. The principle seems not only to be applicable to babbling [Davis and MacNeilage, 1995], but also to early speech [MacNeilage and Davis, 1996]. In babbling, and early speech, consonant-like phones are produced during the closed phase of the cycle and vowel-like phones during the open phase, but neither phone type is considered to be under independent control. Thus, the initial repertoire is one in which the articulator most fully exploited by the infant (who does not yet have good control over the motor system) is the mandible. This view predicts that because the tongue tends to remain in one position during the close-open cycle, the 'consonant' and 'vowel' in a CV sequence in which the tongue is in a nonresting position will tend to be articulated in the same place. Specifically, an infant who begins with a [d] consonant (where the tongue is set high and front in the mouth) will tend to follow the consonant with a front vowel, and a dorsal consonant will be followed by a back vowel. It is also predicted that bilabials will occur with central vowels when the tongue is in a rest position to yield CV syllables designated as 'pure frames' [MacNeilage and Davis, 1990b]. In addition to specific consonant-vowel co-occurrences, the principle of frame dominance predicts that when syllable-to-syllable variation occurs, consonants will differ more in terms of manner than place and vowels will differ more in terms of height than in the front-back dimension, because manner and height differences involve differences in mandibular elevation whereas consonantal place and front-back position differences involve tongue movement. A characterization of consonants in terms of mandibular elevation is as follows: stop and nasal consonants are articulated with a closed mouth, fricatives with a slight degree of aperture, and glides with a larger degree of aperture.

The above claims which arise from the frame dominance view have been evaluated in a total of 99 tests in three papers [Davis and MacNeilage, 1995; MacNeilage and Davis, 1996; Zlatic et al., 1997]. Ninety-one of these tests showed positive results typically at statistically significant levels, six showed countertrends and two showed an absence of trend.

Final consonants in babbling have not yet been investigated with the frame dominance principle in mind. If the frame dominance principle applies to final consonants, they should tend strongly to share place of articulation with the consonant preceding them. Davis and MacNeilage [1995] have found that in CVCV sequences involving stops, nasals, and glides, labial repetition occurred 88% of the time, coronal repetition 86% of the time and velar repetition 74% of the time. If final consonants are as subject to frame dominance as consonants in CVCV sequences, they should yield repetition percentages similar to these. In addition, the vowels between the two consonants in CVC syllables should show the specific co-occurrence tendencies outlined above.

Though the similarity of final consonants to their predecessors has not yet been studied in babbling, a common error tendency in first words, described as consonant 'assimilation', is to make final consonants and their transvocalic predecessors similar in place of articulation (e.g. [bəp] for [bɪg], or [gʊk] for [dʌk]). Some researchers [Fee and Ingram, 1982; Menn, 1983; Berg, 1992] have argued that this pattern in early words is evidence of a cognitive strategy. For example, in Menn's [1983] account, if a consonant is repeated following a vowel, only the first consonant will need to be programmed. The resultant preprogramming of the following consonant yields an overall reduction in programming which makes the production of the segments easier for the infant. (Even though it is likely that Menn [1983] is referring to motor programming, the explanatory account given for consonant repetition is cognitive and not motoric because it is implied that the infant is actively pursuing a particular strategy in production.)

A cognitive approach to segmental repetition would seem to predict that the repetitions be faithful replicates of the first consonant in terms of manner of articulation, voicing, and place of articulation, whereas the frame-related motor approach to consonant repetition applies only to place of articulation – the attribute of consonants most usually cited in examples of assimilation. The motor view is also more compatible with the fact that consonant repetition is frequent in the beginning of babbling (7 or 8 months of age). At this early stage, cognition would potentially be a much less important factor than when production of lexical items is being attempted. Also, Smith and Oller [1981] and Oller and Seibert [1988] have reported that infants with Down's syndrome begin canonical repetitive babbling at the same age as cognitively unimpaired infants and show similar patterns of consonantal and vocalic development. If very young infants and infants with Down's syndrome produce canonical repetitive babbling, it is more likely that these consonants and syllables arise from a simple articulatory routine than from a cognitive strategy of preprogramming individual consonants.

The programming hypothesis, which would, in principle, equally favor repetition of any consonantal attribute, is also inconsistent with a body of evidence that suggests that, in babbling, final consonants tend to differ from initial consonants with regard to the other two main consonantal attributes, namely, voicing and manner of articulation. (In this paper the terms 'voiced' and 'voiceless', when applied to stop consonants, refer to the English phonemic categories /b/, /d/, and /g/ versus /p/, /t/, and /k/.) Final devoicing, which is widespread in babbling, is also a common pattern outside of babbling. For instance, Menn [1983, p. 17] describes the tendency to devoice final consonants as '... one of the most frequent rules in adult language, appearing in many forms from a low-level tendency (as in American English) to the familiar German and Russian final devoicing rule and Turkish syllable-final devoicing'. Menn [1983] also points out that this phenomenon is frequently observed in the first words of infants. It has been suggested that the greater tendency to devoice consonants in absolute final position in adult speech is due to the reduction of subglottal air pressure when approaching the termination of an utterance. The reduction of subglottal air pressure probably results in a loss of a sufficient pressure drop across the glottis to sustain vocal fold vibration [Hock, 1986]. The likelihood that the phenomenon of devoicing has an aerodynamic basis in babbling can be evaluated by determining whether any devoicing tendency interacts with place of articulation of the consonant involved. A well-known rationale for the fact that the ratio of voiceless to voiced stops in languages increases as the place of articulation becomes more posterior [Maddieson, 1988] is that the more posterior the place of articulation, the smaller the air space above the glottis. And a smaller cavity is less able to sustain an adequate pressure drop across the glottis which would be necessary for voicing to continue during the occlusion [MacNeilage, 1982; Ohala, 1983]. A production basis for the pattern of voiceless consonants would be suggested if such an interaction between voicelessness and place of articulation can be found in babbling data for stop consonants.

Another difference between the production of initial and final consonants in babbling concerns manner of articulation – the tendency for fricatives to be produced more often in final position than in initial position [Oller et al., 1976; Oller and Eilers, 1988; Locke, 1983; Kent and Bauer, 1985; Coberly, 1985; though see Stoel-Gammon, 1985]. This tendency is also present in languages [Hock, 1986]. One motor-based account of the production of more syllable-final fricatives is suggested by the hypothesis that devoicing involves a terminal decrease in subglottal pressure. A terminal decrease in subglottal pressure would presumably be the result of a decrease in energy delivered to the component of the respiratory system responsible for the progressive lung volume decreases required to sustain a relatively constant subglottal pressure during an utterance. Perhaps there is a similar decrease in terminal energy delivered to the active articulators which would tend to result in a lower frequency of total occlusion in final consonants. The perceptual correlate of this tendency would be an increase in the frequency of fricatives.

The hypothesis that there is a decrease in the amount of energy expended in vocal production at the end of an utterance also predicts different frequencies of nasals in final versus nonfinal position in babbled utterances. It could be argued that if there was a generalized terminal energy decrease in babbling, more final than nonfinal nasals would be expected. If energy involved in velar closure decreased, the velopharyngeal passage might have a tendency to become open. This would facilitate the continuation of voicing – hence the nasal sound – because it would facilitate continued maintenance of a pressure drop across the glottis even if subglottal pressure was terminally decreasing. A cross-linguistic tendency for there to be more final than initial nasals in languages is in accordance with this hypothesis, but an opposite trend has previously been reported for babbling [Coberly, 1985]. In this study the relative distribution of nasals in initial and final position will be examined in an attempt to determine whether or not a tendency exists in babbling for more final nasal consonants.

To summarize, the aim of the present study is to gather evidence for the possibility that the segmental characteristics of final consonants in the monosyllabic and utterance-final CVC syllables of babbling are largely determined by production constraints. The first hypothesis, arising from the concept of frame dominance, is that the place of articulation of final consonants will tend strongly to be the same as that of the preceding consonants in CVC syllables. This hypothesis also requires the presence of a particular pattern of consonant-vowel co-occurrences, namely, labial consonants with central vowels, coronal consonants with front vowels, and dorsal consonants with back vowels. A second hypothesis is that several other properties of final consonants, reflected in their relative frequencies, are consistent with the possibility of a generalized decrease in the energy delivered to the vocal production system in the terminal phase of a babbling episode.

Methods

The data analyzed in this study were obtained from a corpus [Davis and MacNeilage, 1995] of babbled utterances from 6 normally developing infants identified as C, N, P, R, S, and W. The infants, all from American-English language environments, were taped with an ATW-20 digital audio recorder for 1 h every week in their homes. The infants wore an Audiotechnika ATW-1031 remote microphone attached at the shoulder of a cloth vest. The microphone picked up any vocalizations made by the infants while they engaged in normal activity. The present study utilized data obtained from the 6 infants at the beginning of babbling until early in the 50-word stage, which usually begins at about 12 months of age. There were a small number of CVC words with final consonants in the corpus, but these were not analyzed.

The hourly sessions were transcribed using broad phonetic transcription by the observer who had recorded the infant. There was a different transcriber for each subject with the exception that one transcriber was responsible for 2 infants. While randomizing the allocation of transcribers to individual tapes would have provided a control for transcriber bias, the procedure used made available the transcriber's detailed knowledge of a particular infant. This procedure also provided the opportunity to evaluate any transcriber biases that might have appeared. Intertranscriber reliability was evaluated by selecting sets of approximately 100 utterances produced by each of the 6 subjects which were transcribed by all transcribers. Two separate evaluations were made on the reliability of consonant transcription. One analysis was confined to stops, nasals, glides, and vowels [Davis and MacNeilage, 1995]. Each transcriber transcribed approximately 100 utterances from each subject for whom he/she was not the primary transcriber. Percentages of agreement between transcribers on stops, nasals, and glides ranged from 55 to 87% with a mean of 76.2%. Agreement on vowel front, central, or back dimensions ranged from 55 to 87% with a mean of 73.5%. A separate reliability analysis was made for fricatives, affricates, and liquids [Gildersleeve et al., 1997]. Transcribers for 4 of the subjects (C, R, P, and N) each transcribed a set of 20 utterances from each of the 4 subjects. The mean transcriber agreement for place of articulation of fricatives, affricates, and liquids was 73% and ranged from 70 to 80%. The mean agreement for manner of articulation was 53% and ranged from 48 to 60%. An analysis of voicing reliability was not conducted, but the acoustical measures which are reported in the present study indicate that transcribers were sensitive to differences in voice onset time for stop consonants.

To allow for computer analysis of the babbled utterances, the transcriptions were entered into a database. Computer analysis was carried out using a specialized software program called Logical International Phonetic Program (LIPP) [Oller, 1990]. The data analyzed in this study represented 148 transcribed hours of babbled utterances with a 'speech-like' or rhythmically syllabic quality. The

148 h covered a period from approximately 7 to 13 months of age. CVC syllables which were either monosyllabic or utterance-final were extracted from the transcriptions with the help of a specialized program. All possible combinations of CVCs with 26 different consonants ([b, p, m, β, v, f, w, ð, θ, d, t, n, z, s, j, r, l, ʒ, ʃ, ǰ, ˇc, g, k, ŋ, h, ʔ]) and 7 vowel categories [high front ([i], [ɪ]), mid front ([e], [ɛ]), low front ([æ]), mid central ([ʌ], [ə]), low central ([a]), mid back ([o], [ɔ]), high back ([u], [ʊ]) were analyzed. The consonant and vowel categories chosen covered almost the entire range of sounds produced by the 6 infants. Four percent of the consonants in closed syllables fell into an 'Other' category. Those syllables terminating in [h] and [ʔ] were excluded from the present analysis because [h] and [ʔ] lack an oral place of articulation. A total of 721 CVC tokens were obtained. The number of tokens produced varied across infants. Subject C produced 164 monosyllabic or utterance-final CVCs, subject N produced 76, subject P produced 122, subject R produced 227, subject S produced 64, and subject W produced 68. The infants produced 55% of their CVCs at the end of an utterance, and 45% in monosyllabic utterances.

Acoustical measurements of final stop consonants were made to assist in evaluation of their voicing characteristics. One important consideration was whether the transcribers' judgments of voicing were actually based on the amount of voicing during closure, the parameter germane to the hypothesis that there is an aerodynamic basis for the pattern of voiceless consonants. One alternative possibility to using amount of voicing during closure as a basis for these judgments would be to use another variable important to the adult final voicing distinction in English, namely, differences in vowel duration before voiced and voiceless obstruents. If the duration of preconsonantal vowels were to correlate with the judged voicing of the final consonant, then the hypothesis that there is an aerodynamic basis for voiceless final consonants could not be evaluated. Thus, a subset of the CVC syllables, those consisting of two stop consonants, were acoustically analyzed to insure that transcribers had used amount of voicing as the criterion for transcribing voice and voiceless consonants as opposed to vowel length and to determine whether place of articulation interacted with voicing duration. A total of 211 tokens were isolated from the tapes and analyzed using Kay Elemetrics Computerized Speech Laboratory (Model 4300B). Data were entered in analog form from the TEAC DA-P20 Digital Audio Tape Deck used for recording and transcription into a Kay Elemetrics (Model 4300) external module digitizer on an IBM clone computer system. Because the infants had been taped in their home environment under natural conditions, only 124 of the tokens were uncontaminated by background noise and amenable to acoustic analysis. Of the 124 tokens, there were 33 with final /b/, 30 with final /d/, 10 with final /g/, 11 with final /p/, 26 with final /t/, and 14 with final /k/. Measurements included vowel duration, duration of voicing following consonantal closure, and, when possible, the percentage of voicing duration during the closure from vowel offset to release burst. Vowel duration was measured on the wideband spectrogram. The first broad spectrum pulse was taken as the onset of the vowel, and the offset was taken at the point of marked decrease in the energy of higher formants. Voicing duration during final consonant closure was measured from vowel offset to the last glottal pulse.

Results

Characteristics of the Initial and Final Consonants

Table 1 is a summary of all the consonant transcription data. It is a plot of the frequencies of final consonants (top) against the initial consonants which preceded them (left side). The table is divided into three major blocks which represent the three place of articulation categories: labial, coronal, and dorsal. Coronal consonants represented the largest category of consonants produced by the infants, followed in turn by labials, with relatively few dorsal consonants. The table also shows that a few specific consonants were greatly favored in production. These consonants are [b, m, d, n].

Figure 1 presents the mean percentages of the initial and final consonants for the 6 infants, according to place, manner, and voicing. The relative frequencies for the three places of articulation were extremely uniform for final consonants and for those

Table 1. Occurrences of final consonants (top) plotted against the initial consonants (left side) that preceded them in the CVC syllables.

	FINAL CONSONANTS																								
	Labial							**Coronal**														**Dorsal**			
	b	p	m	w	β	v	f	ð	θ	d	t	n	j	r	l	z	s	ʒ	ʃ	ǰ	č	g	k	ŋ	
b	47	9	10		5	2	2			3	5	14		2			6		5				4		114
p																									0
m	2	2	91	1	1		1			1		5		1			1						2	0	108
w	6	1	5	3						1	3	2							1					1	23
β	1	3			2																				6
v	1					7	1																		9
f											1														1
ð			1					1		2									2			1			7
θ																									0
d	2	4	3	2	1	1	4	4	2	54	42	9	5	5		1	11	2	44	1		4	9		210
t											1		1						2						4
n			8							1	2	59					1						2	4	77
j	3	2	2				1			5	4	1					5	1	16		2	1	1	1	45
r																									0
l	4	2	1							4		3			2		1								17
z																						1			1
s											1						2								3
ʒ											4							1							5
ʃ							1				2						2		5						10
ǰ																			1	1			1		3
č																			1						1
g	1	2	3							2	1	1					1		10		1	12	5	1	40
k			1							1							1		3				1	2	9
ŋ																								2	2
other	1	2	5				5			1			2				1		2			2	4	1	26
	68	27	130	6	9	10	15	5	2	75	66	94	8	8	2	1	32	4	92	2	3	21	29	12	721

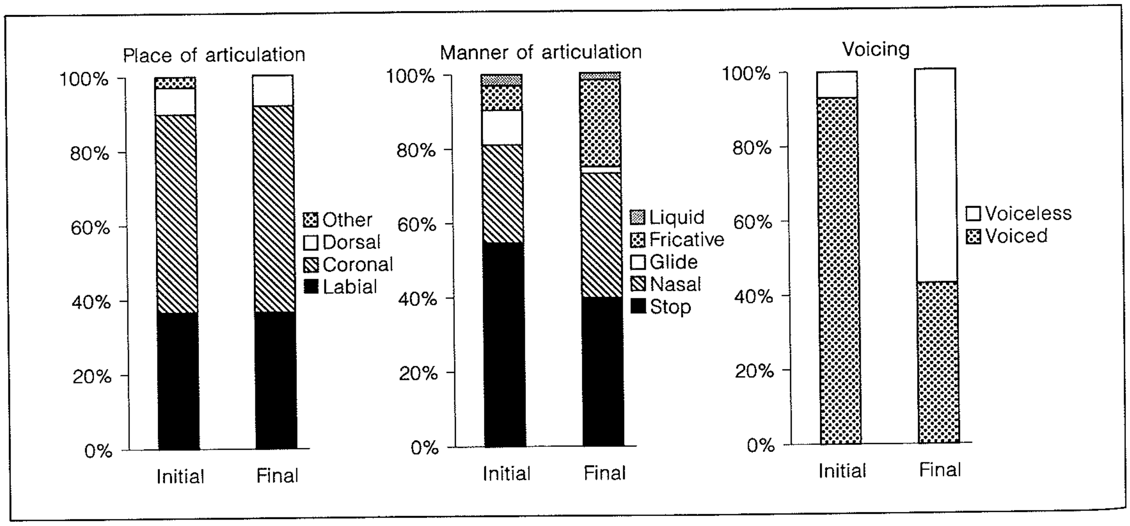

Fig. 1. Frequencies of consonant characteristics expressed in terms of percentages for initial and final consonants.

Table 2. Average duration of vowels and of voicing following consonantal closure, and the average percentage of voicing duration during the closure from vowel offset to release burst

	Voiced	Voiceless
Vowel duration, ms		
Labial	252.4	251.4
Coronal	262.7	268.9
Dorsal	237.6	300.2
Voicing duration following closure, ms		
Labial	63.2	36.1
Coronal	66.8	20.9
Dorsal	96.5	25.8
Percentage of voicing duration during closure		
Labial	42.77	19.14
Coronal	59.61	13.94
Dorsal	60.88	13.44

consonants that preceded them. Coronals were most favored (53% in initial position and 55% in final position), labials were next (36% in initial position and 37% in final), and dorsals were least favored (7% in initial position and 8% in final position). Unlike place of articulation, manner of articulation and voicing varied substantially in the two different syllabic positions. The relative frequencies for manner of articulation are shown in figure 1b. Stops were the most favored consonants, particularly in initial position (53% initial stops, 40% final stops), followed by nasals which were more favored in final position (26% initial nasals, 33% final nasals). All but 1 subject (S) showed this latter tendency. A chi-square analysis showed that the difference between the overall frequencies of initial and final nasals was statistically significant [$\chi^2(1)=5.37$, $p<0.05$]. The panel also shows that fricatives were produced much less frequently in initial position (7%) than in final position (24%) [$\chi^2(1)=70.53$, $p<0.001$]. Finally, with respect to voicing, figure 1c clearly shows that there were many more voiceless consonants produced in final position (57%) than in initial position (7%) [$\chi^2(1)=187.83$, $p<0.001$].

When compared with their homorganic voiced equivalents, voiceless stops in final position occurred relatively more frequently at more posterior places of articulation. The percentages of occurrence of voiceless stops were: labial, 28%, coronal, 47%, and dorsal, 58%. A chi-square analysis showed that the pattern of relative frequencies of final voiceless stops across the three places of articulation was significantly different from the pattern of final voiced stops [$\chi^2(2)=13.58$, $p<0.001$].

Table 2 shows the results of acoustic measurements on final voiced and voiceless stop consonants in CVC syllables with initial stop consonants. Table 2 clearly shows that the perception by transcribers of final voicing was not a function of vowel length. In none of the three cases did the vowels preceding voiced consonants exceed in duration the vowel preceding the voiceless consonants.

Measurements of the duration of voicing following closure for voiced and voiceless final stop consonants in different places of articulation did not confirm the interaction between voicing and place of articulation found in the phonetic transcriptions. There was no statistically significant difference between the duration of voicing in either voiceless or voiced labial, coronal, or dorsal stop consonants [voiceless: $F(2,2)=3.201$, $p<0.15$; voiced: $F(2,3)=0.930$, $p>0.25$]. There was a tendency, how-

Table 3. The percentage of initial and final consonants by place of articulation, manner of articulation, and voicing for each of the 6 subjects

	C		N		P	
	final	initial	final	initial	final	initial
Place of articulation						
Labial	43.29	47.56	25.00	31.58	66.39	62.30
Coronal	49.39	43.29	67.11	61.84	31.97	32.79
Dorsal	7.32	8.54	7.89	3.95	1.64	0.82
Other		15.24		2.63		4.10
Manner of articulation						
Stop	49.39	59.76	32.89	48.68	20.49	22.13
Nasal	42.07	24.39	56.58	43.42	72.95	68.03
Glide	0.61	8.54	0.00	1.32	0.00	5.74
Fricative	7.32	0.61	10.53	2.63	3.28	0.00
Liquid	0.61	6.10	0.00	1.32	3.28	0.00
Other		0.00		2.63		4.10
Voicing						
Voiced	65.59	98.99	51.52	94.87	55.17	100.00
Voiceless	34.41	1.01	48.48	5.13	44.83	0.00

	R		S		W	
	final	initial	final	initial	final	initial
Place of articulation						
Labial	20.70	19.82	31.25	20.31	39.71	35.29
Coronal	70.93	68.28	43.75	50.00	51.47	57.35
Dorsal	8.37	10.57	25.00	7.81	8.82	7.35
Other		1.32		21.88		0.00
Manner of articulation						
Stop	28.19	63.44	64.06	43.75	75.00	66.18
Nasal	12.33	7.49	9.38	14.06	8.82	2.94
Glide	5.29	13.66	0.00	4.69	0.00	19.12
Fricative	52.42	12.78	26.56	14.06	16.18	8.82
Liquid	1.76	1.32	0.00	1.56	0.00	2.94
Other		1.32		21.88		0.00
Voicing						
Voiced	28.96	90.17	25.86	89.19	56.45	98.04
Voiceless	71.04	9.83	74.14	10.81	43.55	1.96

ever, for final voiceless stops with more anterior places of articulation to be of longer duration than those with more posterior places of articulation.

Table 3 breaks down the information presented in figure 1 by subject. The percentages of consonants produced by each of the 6 infants are shown for place, manner, and voicing categories. Table 3 shows that there were considerable individual differences in manner of articulation among the 6 infants, but not in place of articulation or voicing. In terms of manner of articulation, subjects C and N produced mainly stops and nasals in fairly equal proportions. Subject P, however, strongly favored nasals over stops, whereas S and W strongly favored stops over nasals. Subject R deviated

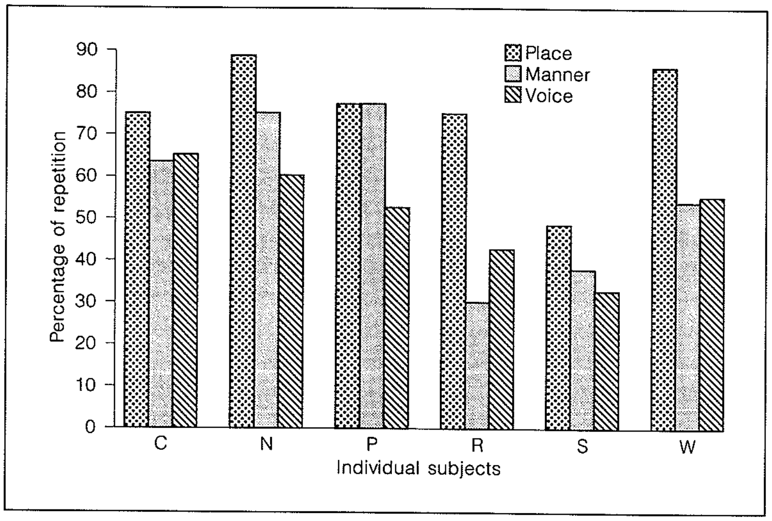

Fig. 2. Percentage of place, manner, and voice repetition for each of the 6 infants.

Table 4. Ratios of observed-to-expected consonant-vowel co-occurrence for CVC syllables with consonant repetition

	CVC co-occurrence		
	front	central	back
Labial	0.41	*1.60*	1.08
Coronal	*1.40*	0.58	0.98
Dorsal	0.73	1.40	*0.67*

The cells for which an observed-to-expected ratio of greater than 1 was predicted are in italics.

most from the other subjects in manner of articulation. R produced a larger percentage of fricative consonants in final position, mostly after an initial coronal stop and front vowel, than either stops or nasals.

Subjects were relatively uniform in their preference for coronal consonants over labial and dorsal consonants in initial and final syllable position. The exceptions to this pattern were P, who preferred labials to coronals, and C, who did not strongly prefer one place of articulation over another. All subjects showed the same preferences for place of articulation in both initial and final position.

The ratio of voiced to voiceless sounds across syllable position was also similar across subjects. All subjects produced more voiceless consonants in final position than in initial position. Subjects did differ, however, in their relative production of voiced and voiceless consonants in final position. Subjects R and S produced many more voiceless final consonants than voiced final consonants, whereas C produced more voiced than voiceless final consonants. The other 3 subjects produced a similar number of voiced and voiceless consonants in final position.

Consonant Repetition and Consonant-Vowel Co-Occurrences

With respect to consonant repetition, examination of initial and final consonants within individual CVC syllables revealed that initial and final consonants had the same place of articulation in 76% of the CVCs. Closed syllables which had labial final consonants had labial initial consonants 77% of the time, closed syllables with coronal final consonants had coronal initial consonants 81% of the time, and those with dorsal final consonants had dorsal initial consonants 39% of the time. With one exception, individual subjects were quite uniform in the high frequency with which they repeated place of articulation (fig. 2). The overall percentages for the 6 subjects were 88 (C), 86 (N), 77 (P), 74 (R), 74 (W), and 48 (S). A chi-square analysis of the observed repetition rates revealed that the observed rates were much larger than would be predicted from the repetition rates expected from the overall percentages of labial, coronal, and dorsal consonants in initial and final position [χ^2 (2)=275.88, p<0.001].

Figure 2 shows the rate of consonant repetition in terms of place, manner, and voicing for the 6 subjects. Overall, consonant repetition was lower in manner and voicing than in place of articulation (53.5 and 49.6 versus 75.7), but subjects differed in the extent to which repetition in place was favored over repetition in manner and voicing.

Table 4 presents data on observed-to-expected ratios of consonant-vowel co-occurrence in the CVC syllables with consonant repetition pooled across the 6 subjects. The expected frequencies were derived for each cell by multiplying the frequency of each consonant category (expressed as a proportion) in the cell's consonant category (labial, coronal, and dorsal) by the frequency of the cell's vowel category, similarly expressed, and multiplying the product by the total number of syllables. For example, if the proportion of labials in the corpus was 0.36 and the proportion of front vowels was 0.15, the expected frequency of syllables with labials and front vowels was $0.36 \times 0.15 \times 721 = 39$ syllables. CVC syllables consisting either of labial or of coronal consonants showed the expected co-occurrence patterns, namely labials with central vowels and coronals with front vowels. Chi-square tests resulted in significance for labial consonants [χ^2 (1)=63.3, p<0.001] and coronal consonants [χ^2 (1)=46.33, p<0.001]. The chi square for velar consonants was not significant.

Discussion

Overall, the initial and final consonant repertoires of the 6 infants in this study show some of the most well-known sound patterns which have been described for infant babbling. Specifically, the 6 infants in this study produced fewer final consonants than initial consonants, and more coronal and labial stop and nasal consonants than dorsal or fricative and liquid consonants. There was also a tendency to favor coronal stops over labial stops. Further, fricative and voiceless consonants were far more prevalent in final position than initial position. Nasals were also somewhat more frequent in final position. This latter result, however, was contrary to Coberly's [1985] finding that nasals were not necessarily preferred in final position in babbling.

A strong effect of frame dominance on place of articulation of final consonants was observed. All individual subjects showed a significant tendency for place of articulation of final consonants to be the same as the preceding consonant. The effect was particularly marked for labials and coronals. Strong consonant-vowel co-occurrence constraints were also observed in labial and coronal contexts. The tendency toward labial and coronal place repetition and the consonant-vowel co-occurrence patterns were similar in strength to those already observed in CVCV sequences [Davis and MacNeilage, 1995]. Thus, in terms of place of articulation, and relations with the adjacent vowel, labial and coronal final consonants showed no more independence from the frame than consonants in other syllabic positions.

Dorsal consonants were not as influenced by the repetition patterns as labial and coronal consonants were. Additionally, dorsal consonants did not show the predicted tendency toward preferential co-occurrence with back vowels in CVC syllables. The evaluation of dorsal consonant trends in babbling is problematic at the moment because transcription reliability for dorsal consonants and back vowels in this corpus was a good deal lower than for the other categories [Davis and MacNeilage, 1995]. Dorsal consonant and back vowel regions of the consonant and vowel spaces in babbling require an acoustic study to clarify the bases of disagreement in transcriber judgment.

In contrast to place repetition, manner and voicing repetition occurred less frequently. The lower levels of manner and voicing repetition are consistent with the frame dominance view which predicts that consonants will tend to repeat place of articulation, but not manner of articulation and voicing. On the other hand, the competing explanation for consonant repetition which views consonant repetition as a cognitive strategy would have predicted equal levels of consonant repetition for place and manner of articulation as well as for voicing.

It is of interest to note that while the place repetition phenomenon is prominent in babbling, and remains about equally prominent in the first words [MacNeilage and Davis, 1996], it is not common in languages. In a cross-language study, Vihman [1978] found very little evidence for this tendency. Berkeley [1994] conducted a chi-square analysis, simlar to the one in the present study, of the relation between observed and expected repetition rates for labial, coronal and dorsal consonants in monosyllabic CVC English words. She found that place repetition occurs significantly *less* often than would be expected from the consonant frequencies in the language. It therefore appears that consonant repetition reflects a constraint that speakers must and normally do surmount in learning a language. Locke [1983] has suggested that this constraint may not remain in language because speakers can more readily coarticulate a consonant with a transvocalic consonant having a different place of articulation which facilitates the development of faster speaking rates. But whatever the reason for its disappearance in adult speech, the prominence of consonant repetition in the early stages of speech acquisition directs attention to the question of why it occurs and exactly how infants eventually surmount it.

As indicated in the 'Introduction', another motivation for the study was to evaluate the claim that the level of energy provided to the speech production system is reduced at the termination of an utterance. The fact that there was an increase in the proportion of voiceless stops in final position which was roughly paralleled by the increase in the proportion of voiceless fricatives is consistent with the hypothesis that both consonantal attributes are similarly affected by a terminal reduction in subglottal pressure. The increase in the proportion of fricatives in final position could perhaps be attributed partially to a reduction in the amplitude of the mandibular closing phase and partly to a reduction in amplitude of any active constriction gesture being made – by the lips, for labial consonants, and by the tongue for lingual consonants.

There is some evidence from other studies for the hypothesis that there is a terminal energy decrease in the respiratory and/or phonatory components of early infant vocalizations. Stark et al. [1975] observed a tendency for the fundamental frequency (F_0) to fall in noncry, prebabbling vocalizations of infants in English language environments. Kent and Murray [1982] and Whalen et al. [1991] have reported a similar phenomenon for both prebabbling and babbling. In a study on the acoustic correlates of stress in the vocalizations of 4 of the 6 subjects from the present study, a significant tendency for a lower intensity in the final syllable of disyllabic utterances was observed [Davis et al., 1997]. There was also a nonsignificant trend towards a lower F_0 in the second syllable. All these tendencies are consistent with the claim that subglottal pressure may decrease at the termination of babbled utterances. This early effect may be a cornerstone of speech production. Lieberman [1984] has argued that there is a universal tendency towards a terminal decrease in F_0 and intensity in languages, and considers it to be inherent in human vocalizations.

In light of the disagreement between the present study and that of Coberly [1985], more evidence is needed in order to answer the question of whether there are more nasals in final than in nonfinal position. The issue of the relative frequency of nasals in final and nonfinal position is central to the two theoretical explanations proposed in this paper to account for final consonant characteristics in babbling. Final denasalization following a nasal initial consonant would be contrary to the frame dominance principle which predicts that, with the exception of the mandible, the articulators are involved in a minimum of systematic changes across an utterance. Final denasalization would also be contrary to the hypothesis of a terminal energy decrease because it would require an additional final act – the raising of the velum – rather than a decrease in energy. In the present study it was observed that there were more nasals in final position than in initial position. One fact that makes this result convincing is that it was superimposed on a high tendency for nasalization to be sustained across the syllable. Eighty-nine percent of initial nasals were followed by final nasals. This probably resulted from a maintenance of nasality rather than from a reintroduction of nasality after a nonnasal vowel. It was found in an acoustical study on the babbled utterances of 4 of the 6 infants from the present study that when two nasal consonants surrounded a vowel, the vowel is heavily nasalized [Davis and McNeilage, 1995].

To summarize the foregoing discussion, a number of findings in this study and in other studies converge on the possibility that there may be a generalized energy decrease in the vocal production system of babbling infants towards the termination of an utterance. This decrease may affect the respiratory, phonatory, and articulatory systems in similar ways. The fact that some of the resultant acoustical properties of the utterances are also widely observed in the languages of the world suggests that the tendency might be quite fundamental to speech production. If so, it provides additional evidence that the study of sound patterns in babbling is important for understanding speech.

In conclusion, it has been suggested that the characteristics of final consonants in babbling might be understood as primarily arising from two types of production constraints. The place of articulation of final consonants might be largely a result of the relatively uniform oscillation of the mandible (frame dominance) throughout an utterance, with other articulators in a more or less constant resting or nonresting position. Final consonant voicing and manner characteristics may be modified in the direction of voicelessness, frication or nasalization because of an overall terminal energy decrease in the vocal production system. The tendency of frame dominance to produce consonant place repetition is largely overcome in the more variegated forms of adult speech, but it would appear from the cross-language data that at least some effects of the terminal energy decrease persist.

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