

# The Articulatory Basis of Babbling

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This article evaluates the “Frames, then Content” hypothesis for speech acquisition, which states that much of the patterning of babbling is a direct result of production of syllabic “Frames” by means of rhythmic mandibular oscillation, with relatively little of the intrasyllabic and intersyllabic “Content” of the syllable-like cycles under mandible-independent control. Analysis was based on a phonetically transcribed corpus of 6,659 utterances of 6 normally developing infants obtained from one-hour weekly audio-recordings over a 4–6 month period. Intrasyllabic predictions were that front vowels would preferentially co-occur with front (alveolar) consonants, back vowels with back (velar) consonants, and central vowels with labial consonants, with the latter effect presumably resulting from mandibular oscillation alone. Intersyllabic predictions were for more variegation in tongue height for vowels than in front-back tongue movement, and for consonant manner changes to predominate over place changes (related primarily to mandibular oscillation). All 30 individual predictions from both hypotheses were confirmed, leading to a conception of the articulatory basis of babbling as “Frame Dominance.”

**KEY WORDS:** babbling, speech development, motor control, normal, English language

Canonical babbling first occurs around 7–8 months of age (Holmgren, Lindblom, Aurelius, Jalling, & Zetterstrom, 1986; Koopmans-van Bienum & Van der Steldt, 1986; Oller, 1980; Stark, 1980). Canonical babbling can be characterized as phonation accompanied by an alternation of closed and open phases of the mouth within spatio-temporal timing patterns appropriate for adult utterance strings. The characteristic of babbling most striking to the listener, from the onset, is rhythmicity, indicating the presence of timing uniformity throughout utterances. In a typical case, patterns resulting from consonant-like closing phases of low energy and short duration alternating with vowel-like phases of higher energy and longer duration produce the impression of a regularly timed sequence of consonant-vowel syllables.

Contrary to Roman Jakobson’s assertion (1968) that there is no relation between babbling and early speech forms, recent work has shown continuity between the two (e.g., Vihman, Ferguson, & Elbert, 1986; Vihman, Macken, Miller, & Simmons, 1985). With few exceptions, output patterns in babbling correspond to output patterns in first words. Evidence of continuity from prelinguistic behaviors to early words in both sound preferences and temporal organization increases the importance of understanding babbling as a crucial first phase of development toward adult speech production ability.

Despite its apparent importance in understanding speech development, there has been relatively little work on the overall organization of utterances in the babbling stage. Questions regarding whether vowels tend to preferentially co-occur with certain consonants within syllables, how vowels change from syllable to syllable, and whether such changes relate systematically to the surrounding consonants have not been frequently addressed. Because sound organization preferences in babbling presumably relate to preferences in early words, this matter would seem to deserve attention.

Although consonants and vowels are probably not controlled as separate entities

in babbling, most basic facts about babbling have come from phonetic transcription studies using these categories. These studies have shown strong similarities in sound preferences across different communities, suggesting a universal basis for babbling (e.g., Locke, 1983; Roug, Landberg, & Lundberg, 1989). Consonantal phones most frequently reported are stops [b], [d], and sometimes [g];<sup>1</sup> nasals [m], [n]; and glides [j], [w], and [h] (Locke, 1983; Stoel-Gammon 1985; Vihman et al., 1985). Mid and low front and central vowels [ɛ], [e], [a], [æ], [ɔ], [ʌ] are most often reported in both transcription studies (Kent & Bauer, 1985; Davis & MacNeilage, 1990; Stoel-Gammon, 1990) and acoustical studies (Bickley, 1983; Buhr, 1983; Kent & Murray, 1982; Lieberman, 1980). Most frequent syllable types are consonant vowel (CV) syllables either occurring alone or in series.

A standard view of the period between onset of canonical babbling and first word use is of an initial stage of reduplicated babbling, consisting of sequences of identical CV syllables, followed by variegated babbling in which different segments occur in successive syllables (Elbers, 1982; Oller, 1980, 1986; Roug, Landberg, & Lundberg, 1989; Stark, 1980). In contrast, Smith, Brown-Sweeney, and Stoel-Gammon (1989) and Mitchell and Kent (1990) found no clear separation between use of reduplicated and variegated babbling in subjects before first words. These studies considered consonant series in multisyllabic utterances. These results suggest that the entire babbling period may be similar to the period of first words in containing both reduplicated and variegated forms.

MacNeilage and Davis (1990a, 1990b, 1993) have proposed “Frames, then Content” as a metaphor to describe spatio-temporal and biomechanical characteristics of babbling and changes during early speech. The term *Frame* applies to the regularity of mandibular oscillation resulting in listener perception of syllable-like and therefore speech-like output. It is claimed that close and open phases of the cycle often may have no associated neuromuscular activity other than movement of the mandible and consequently may have no subsyllabic organization or Content. In this view, the syllabic Frame thus constitutes the earliest temporal envelope within which segment-specific Content elements develop as the child gains increasing independence of control over speech articulators in speech movement sequences.

If Frames initially predominate over Content, then particular co-occurrence patterns in contiguous consonants and vowels, due to mechanical characteristics of jaw movement and relative lack of lingual independence, are predicted. Davis and MacNeilage (1990), in a transcription-based case study of a child between 14 and 20 months old, found co-occurrence patterns between consonants and vowels to be maintained during a period in which the subject developed from 25 to 750 words. Consonant-vowel co-occurrences were found for alveolar consonants with front vowels, labial consonants with central vowels, and velar consonants with back vowels. Another 7–12-month-old infant studied

during the babbling period (Davis & MacNeilage, 1994) also showed very strong co-occurrence patterns for sequences of front vowels with tongue front consonants and central vowels with labial consonants. This infant produced few velar consonants and back vowels.

Acoustic evidence supports the claim that there may be minimal changes in articulators across CV sequences. In a study of coarticulation in children 3 and 7 years old, Nittrouer, Studdert-Kennedy, and McGowan (1989) found greater difference in the second formant within the fricative noise depending on the quality of the upcoming vowel in children’s syllables than in adult syllables. In a subsequent study (Nittrouer, in press) spectral analysis showed that children 3, 5, and 7 years of age moved away from the consonant closure more slowly and initiated the vowel gesture sooner than did adults for stop-vowel sequences. Nittrouer suggested that the curves used to depict individual signal components might be envisioned as being flatter, broader, and as having more shared areas in children’s than in adults’ syllable productions, reflecting less autonomy and more temporal and gestural coarticulation.

Hypotheses regarding co-occurrence patterns in canonical babbling and early speech have been subject to transcription-based studies with differing results. One difficulty in comparing data across studies is lack of information regarding precise definition of consonant place and vowel height and front-back categories used in each study. Consistent use of categories would help to evaluate this type of hypothesis more fully.

Vihman (1992) studied co-occurrence patterns in a group of 23 children in four different language communities in the period of the first 50 words. The claim that there are labial-central vowel and velar back vowel co-occurrence constraints was largely supported, but the claim of an alveolar front vowel association was not strongly apparent. However, Vihman’s data analysis included [æ] as a central vowel, complicating findings on alveolar-front vowel associations. The source of negative association of alveolars and front vowels was three English-speaking and two Swedish-speaking subjects. Vihman noted the strong role played by the individual child at this developmental stage of first word use, suggesting that lexical use might predominate over biological or physiological factors in contrast to the situation at the onset of canonical babbling.

Boysson-Bardies (1993) studied groups of five 10–12-month-old infants from four different language communities (French, English, Swedish, and Yoruba). She found predicted CV patterns in the infants to be influenced by characteristics of the target language (calculated “on the basis of words that 18 month old infants attempt in each language group,” p. 358). Labial-central vowel association in initial syllables was found for French, Swedish, and Yoruba infants. American infants showed an association between labials and front vowels. A favored association between dentals and front vowels was found in English, Swedish, and French; between dentals and central vowels in Yoruba. Where infants differed from predicted patterns, Boysson-Bardies suggested influence of the ambient language as being characteristic of the resulting patterns.

Oller and Steffans (1993) noted some association of

<sup>1</sup>The symbols [b], [d], and [g] are used to designate stops that are voiceless and unaspirated in initial position but voiced intervocally.

consonants and vowels within syllables in a study of four children 10–12 months. Coronal consonants were more frequently associated with front vowels, dorsals more frequently with back vowels. Coronals showed the greatest association with high vowels, labials the greatest association with low vowels. By 16–24 months, CV associations in the subjects had weakened, consistent with systematic development toward more segmental function, according to the authors.

The importance of understanding babbling is increased by the fact that certain babbling preferences are also present in the world's languages. The CV syllable, the favored syllable type of babbling is considered to be the only universal syllable type in languages. Consonants favored in babbling—simple stop consonants and nasals—are highly frequent in the world's languages (Maddieson, 1984) and tend to dominate the repertoire of languages with small systems (<15 phonemes) containing a few segments characterized as articulatorily “simple” (Lindblom & Maddieson, 1988; Lindblom, Krull, & Stark, 1993).

There is also evidence that certain CV co-occurrence patterns found in babbling are also common in languages. In an analysis of CV relationships that combined evidence from two studies of different sets of five widely varying languages (Janson, 1968; Maddieson & Precoda, 1990), MacNeilage and Davis (1993) found evidence for the existence of common tongue-fronting and common tongue-backing but not of the co-occurrence constraint involving labial consonants and central vowels. These results raise the possibility that the tongue-based constraints postulated for babbling and early speech may have an extremely fundamental status. They also raise the question of why the co-occurrence constraint between labials and central vowels is not present in adult speech.

The “Frames, then Content” metaphor also has implications for patterns of variegated babbling. From the Frame/Content perspective, changes in amplitude of the mandibular cycle would result in *height* changes for vowels (e.g., [æ] versus [i]) and *manner* changes for consonants (e.g., [d] versus [j]). Thus, a “variegated” utterance (e.g., [dæjæ], [bawə], or [dædɛ], [babʌ] where either consonant or vowels types change across the utterance) would result when mandibular amplitude changes occurred within a sequence. In contrast, a sequence would be “reduplicated” (e.g., [dædæ], [baba] where both consonant and vowel types remain the same across the utterance) when mandibular amplitude remained constant across successive close-open cycles. It is predicted that this source of mandibular variegation will be observed more frequently than the other major possible source. The second source would be changes in tongue position to produce a more front or more back sound quality in the oral cavity for either vowels or consonants or both.

Available evidence from transcription-based studies is inconsistent on the nature of variegation. Elbers (1982), in a study of her child's babbling between 6 and 12 months, found babbling processes to occur in a fixed order; single-syllable babbling, reduplicated babbling, manner changes, then place changes for each of the three places of articulation: front, central, and back. Smith, Brown-Sweeney, and

Stoel-Gammon (1989) studied reduplicated and variegated babbling in 10 subjects at 6–9, 10–13, and 14–17 months. They analyzed consonant place changes as indices of variegation in multisyllables. An additional post hoc analysis including manner variation for consonants showed the following rank orderings: reduplication, place variegation, and manner variegation at 6–9 and 10–13 months; place variegation, manner variegation, and reduplication at 14–17 months. Mitchell and Kent (1990) found manner changes to predominate over place changes in babbling of eight infants studied at 7, 9, and 11 months. Frequency of multisyllables, in rank order, were reduplication, manner changes, mixed place and manner changes, and place changes. Boysson-Bardies (1993) focused on vowel changes in CVCV babbling for infants in four language groups (Swedish, French, American, Yoruba). She found a strong trend for V1 and V2 to agree in height and frontness. In instances where V1 and V2 did not agree, Boysson-Bardies found equal height and front/back changes in three of the four languages. However, height of vowels more consistently agreed with patterns in the adult reference samples than did front/back position, suggesting “more control of height dimension than front/back” (p. 357). Acoustic studies of early babbling have provided support for the idea of a predominance of mandibular over lingual movement in early canonical sequences. Bickley (1983) in a study of vowel development in 14 infants at 3-month intervals between 14 and 22 months found evidence for the development of vowel height before vowel backing. She interpreted her results as a demonstration that infant control over degree of mouth opening (F1) precedes the ability to control anterior-posterior positioning of the tongue body (F2). Hodge (1989) studied 7.5–9.5-month-old infants' spontaneous vocalizations, and imitated CV syllable productions in 3-, 5-, 9-year-old, and adult speakers. She proposed that patterns of displacement for first and second formants suggest younger children are accomplishing opening and closing gestures with greater relative contribution of mandibular than lingual movement, whereas older children and adults are using a greater relative contribution of tongue versus jaw movement. Specifically, she found less movement of F2 trajectories in younger age groups, suggesting a relatively smaller amount of change in place of major constriction in the vocal tract on the front-back dimension. Results of formant frequency measurements of schwa-stop-vowel sequences in adults and children 3-, 5-, and 7-years of age (Nitttrouer, 1995) showed that vocal tract close and open phases achieved adult-like patterns of movement by age 3; tongue gestures were constrained by phonetic context until the age of 7.

One problem with much of the work on babbling patterns is that it often involves small numbers of observations per subject and pooling of data across subjects who might be quite different, thus making it difficult to assess the generality of trends. It is possible that at least some of the discrepancies between the results of different studies are due to these methodological factors. An aim of the present study is to investigate this possibility by analysis of relatively large databases (more than 1,500 tokens) for each of a number of subjects (6). In this study predictions will be tested from the two hypotheses described earlier, as follows:

1. CV co-occurrence hypothesis—There will be a significant tendency for patterns of co-occurrence between successive consonants and vowels within an utterance.
  - A. central vowels in the environment of labial consonants
  - B. front vowels in the environment of alveolar consonants
  - C. back vowels in the environment of velar consonants
2. Variegation hypothesis—There will be a significantly higher proportion of consonant and vowel changes (within utterance) in the vertical dimension than in the horizontal dimension.
  - A. vowel differences will be in height rather than in the front-back dimension (i.e., [dædi] not [dædɔ])
  - B. consonant differences will be in manner rather than place (i.e., [bawa] not [bada])

## Method

### Subjects

Data analyzed for this study were collected as a part of a longitudinal project tracking early normal speech development from the onset of canonical babbling through age 3½. Six normally developing infants, 3 males and 3 females, from English monolingual homes were included. Subjects were located by informal referral from the surrounding community. Normal development was established through parent case history report. In addition, each infant was administered the Battelle Developmental Screening Inventory (Guidubaldi, Newborg, Stock, Svinicki, & Wneck, 1984) and hearing screening using sound field techniques. Two infants were only children, and 4 had one sibling. Table 1 summarizes subject descriptive data.

### Data Collection

Following initial contact when the infant was approximately 6 months of age, parents were interviewed weekly by phone about their infant's sound productions. Data collection was initiated on parent report of reliable appearance of canonical syllables. Age of onset varied between 6.5 and 8 months.

Five observers collected and analyzed data for the 6 infants. Each observer tracked the same infant over the course of the study. One-hour weekly sessions were audio-

taped in the subject's home. In 3 infants, the sampling period was coextensive with the preword babbling period; the other 3 infants had not yet begun to produce words at the end of the sampling period. An ATW-20 digital audio recorder was used for both data collection and subsequent transcription. Each infant wore an Audiotechnika ATW-1031 remote microphone in a cloth vest. The microphone was clipped at the shoulder to keep a consistent mouth to microphone distance and to discourage the infant from handling the microphone. No structure was imposed on the normal household routine. The observer was always present and interacted with the parent informally. In addition, family members or guests were occasionally present.

### Data Analysis

Data selected for analysis included all speech-like canonical babbling occurring during the 1-hour sessions. Vocalizations analyzed were produced with minimally a consonant-like closure phase (articulatory obstruents, sonorants, and glides) and a vowel-like open phase within a single utterance string. This criterion resulted in either CV or VC monosyllables as minimal units for analysis; polysyllables included CV or VC alternations. The phone [h] was included when it was present in rhythmically alternating sequences. All utterance strings analyzed were comfort state vocalizations produced without conspicuous background noise or speech. Tokens selected as single utterance strings were bounded by 1 second of silence, noise, or adult vocalization. Singleton consonants (e.g., [m]), vowels (e.g., [a]), and vegetative or nonspeech vocalizations such as burps, coughs, cries, or raspberries were excluded from this analysis.

All utterances that met these criteria were phonetically transcribed by the primary transcriber for each infant. Broad phonetic transcription was used, supplemented by diacritics available for infant speech (Bush et al., 1973; Oller, 1990). Transcription training sessions were held before the start of the study to ensure consistent transcription conventions. Consonants were grouped within the labial ([b, p, m, w]), alveolar ([d, t, n, j]), and velar ([k, g, ŋ]) places. The palatal glide [j] was classified as alveolar. Only stops, nasals, and glides were used for the main analysis, as fricatives, liquids, and other oral consonant sounds tend to occur with extremely low frequencies in babbling (Locke, 1983). Other phones were grouped into an "other" category. Glides were considered to be consonants for this analysis because they shared the consonantal property of accompanying the mouth-closing phase of babbling. The glide [w] was classified as labial because the paucity of high back vowels in babbling suggests that the usual velar component of this glide is probably not prominent in babbling. Vowels were grouped into front, central, and back categories. Vowels were transcribed using symbols for individual vowel types in the following categories: high front [i, I], mid-front [e, ε], mid-central [ʌ, ə], low front [æ], low central [a], high back [u, ʊ], and mid back [ɔ, o]. Low back vowels were not included in the analysis as they occurred very infrequently in the corpus—as was the case for fricative and liquid consonants.

All transcribed data were entered using a phonetic key-

**TABLE 1. Summary of subject variables and numbers of recording sessions per subject.**

Subject	Onset age (months)	Gender	Siblings	#Sess
C	7.0	F	1	14
R	7.0	F	1	20
N	8.0	M	1	19
P	6.5	M	1	19
W	6.5	M	0	17
S	6.0	F	0	14

board and software developed for analysis of infant data (Logical International Phonetic Programs; Oller, 1990). Resulting analyses included variations of basic analyses available using the LIPP program. Consonant and vowel counts and percentages were produced for each subject. Inventories of syllable types and average length of utterance strings were also listed. Sequential consonant-vowel association was assessed by counting consonants grouped into labial, alveolar, and velar places; vowels were grouped into front, central, and back categories. Characteristics of variegated polysyllables were assessed by a program utilizing Macintosh software. The program produced counts for all possible permutations of vowel and consonant polysyllabic combinations. The analysis of the relative frequency of reduplication and variegation was performed on each pair of successive CV syllables in the corpus. In utterances of more than two syllables, each syllable was analyzed twice; once as the first of two syllables and once as the second. If the two syllables were the same, the sample was considered reduplicated. If the two syllables differed in the vowel or the consonant or both, the sample was considered variegated. Criteria for vowel differences were height changes and front-back changes. Criteria for consonant changes were either place or manner changes. Voicing changes were not analyzed in this study. Note that this criterion is less demanding for the incidence of variegation than if entire utterances are classified as reduplicative or variegated. Using the latter method, a single departure of a consonant or a vowel from reduplication leads to an entire utterance being classified as variegated, regardless of length.

### Reliability

In this study a single transcriber was assigned to each infant. One transcriber followed two infants. Rather than randomizing the allocation of transcribers to individual tapes, the transcriber's detailed knowledge of a particular subject was available. There was also the opportunity to isolate transcriber biases. Transcription reliability was calculated in several ways. Initially, the point-to-point method

was used to calculate the percentage of times that a second transcriber transcribed consonants or vowels in the same way as the primary transcriber without reference to the results for individual sounds. A second type of analysis involved comparing individual phones and the patterns of difference. Transcriber biases also examined using a procedure whereby each of the five primary transcribers transcribed a sample of approximately 100 utterances from a tape of each of the 5 infants. Each sample was taken from a period at least 2 months after the onset of canonical babbling to ensure a plentiful supply of canonical syllables. Only the symbols grouped as described earlier were included in this analysis. A total of 2,218 consonants and 2,020 vowels were transcribed.

## Results

### General Summary

**Utterance structures.** Table 2 displays frequency of occurrence for segment and utterance types. Overall number of segments analyzed for this study totaled 31,458 for all 6 subjects. For 5 of the 6 subjects, number of vowels exceeded those of consonants. None of the differences between consonant and vowel totals was more than 12% (range 2.5%–12%), reflecting a balance between close and open phases, lack of consonant clusters, and use of open syllables. Number of utterances for all subjects was 6,659, ranging from 704 to 1,458. Syllable total was 14,431, ranging from 1,434 to 2,939. Monosyllables were more common than disyllables among all 6 subjects—in most cases by a ratio of at least 2:1. Multisyllables accounted for the largest number of utterance types produced. Overall, monosyllables accounted for 15%, disyllables 7%, and multisyllables 78% of utterances produced in the entire corpus. No individual multisyllabic type was preferred more than disyllables. There were no individual departures from group trends.

**Consonant characteristics.** All consonant categories occurring with a frequency of 5% or greater are listed in

**TABLE 2.** Frequency of occurrence of segments, syllables, and utterance types in the entire corpus.

	Segments		Utts	Total sylls	Polysylls		
	Type	Total			Monosylls	Disylls	Multisylls
C	C 2752 V 2825	5577	1458	2771	581	351	1839
R	C 2577 V 2933	5510	1326	2798	448	201	2149
N	C 3016 V 2787	5803	1065	2508	279	129	2100
P	C 1411 V 1516	2927	704	1434	265	89	1080
W	C 3514 V 3409	6923	1054	2939	211	107	2621
S	C 2420 V 2298	4718	1052	1981	398	114	1469
Total		31,458	6659	14,431	2182	991	11,258

**TABLE 3. Percentages of various consonantal categories (>5%) and total number of consonants produced by each subject.**

Subject											
C		R		N		P		W		S	
Segmt.	%	Segmt.	%	Segmt.	%	Segmt.	%	Segmt.	%	Segmt.	%
[d]	30.4	[d]	32.2	[d]	28.1	[m]	33.4	others	37.6	others	60.4
[b]	22.5	others	22.7	[b]	16.6	[d]	25.2	[d]	20.1	[d]	7.0
[n]	9.7	[j]	15.5	[g]	13.8	[n]	13.4	[b]	13/2	[w]	7.0
[g]	8.9	[g]	9.7	[n]	10.4	other	11/8	[w]	7.2	[g]	6.9
[j]	8.2	[b]	6.3	other	8.8	[b]	5.5	[g]	6.9		
[w]	6.5			[ŋ]	8.6						
Total	2752		2577		3016		1411		3514		2420

Note. Overall total = 15,690.

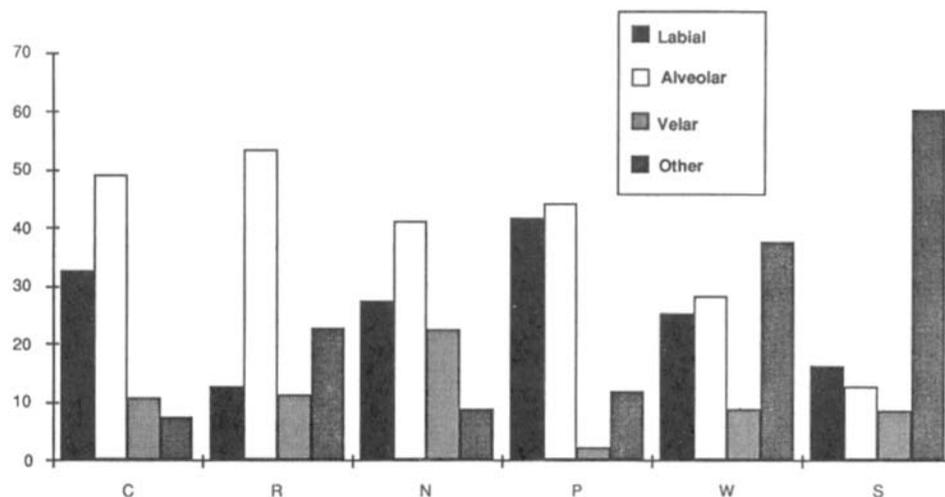
Table 3. Overall, 15,690 consonants, including those occurring less often than 5%, were transcribed for the entire group of subjects. Number of consonants ranged from 1,411 to 3,514. For consonants occurring >5%, use of two types accounted for 45%–55% of all consonants tabulated for four subjects (C, R, N, P). The alveolar stop [d] accounted for the largest single category of consonant type produced for 3 of the 4 subjects (C: 30.4%; R: 32.2%; N: 28.1%). Labial nasal [m] was produced with highest frequency by the fourth subject (P: 33.4%). For the remaining two subjects, consonant types from the “other” category were produced with the highest frequency of occurrence within this category. S produced 69.3% bilabial fricatives, 21% velar fricatives or uvular stops, and 9.7% fricatives and retroflex consonants at the alveolar place. W produced 87% bilabial fricatives, 7.1% uvular stops and velar fricatives, and 5.8% alveolar fricative and alveolar retroflex articulations. For all subjects, frequency of occurrence for consonant types rank ordered below the top two consonants ranged from 5.5% to 15.5%. Nasal stops and glides were most characteristic of low frequency of occurrence types across subjects.

Group and individual trends for place and manner of articulation were apparent. Figure 1 displays percentage-of-occurrence figures for place of articulation for all consonant types in the entire corpus. The categories labeled labial,

alveolar, and velar are those specified earlier. Overall, alveolars and labials were strongly represented, although individual subjects varied in relative occurrence of the two. Velar place of articulation was the least frequent occurrence for all subjects except S, who produced velar and uvular consonants in the “other” category.

Figure 2 displays percentage of occurrence figures for manner of articulation for all consonant types in the entire corpus. Oral stops were the most prominent for most subjects. Least frequently employed manner categories included nasals for three subjects, glides for two subjects, and “other” for one subject. All fell below 10% frequency of occurrence. Overall, oral labial and alveolar stops were most frequent; nasal stops less frequent, except for P; fricatives infrequent, except for S and W; glides present, but not frequent for any subject.

**Vowel characteristics.** All vowel types occurring with a frequency of >5% are listed in Table 4. Overall, 15,709 vowels, including those occurring less than 5%, were transcribed for the entire group of subjects. Number of vowels ranged from 1,411 to 3,514. In contrast to consonant types, no single vowel type strongly characterized all subjects. No vowel type was used with higher than a 30% frequency. For 4 subjects, two or three vowels accounted for 50% of types. For the remaining 2 subjects, frequency was spread evenly

**FIGURE 1. Consonant place of articulation: percentage of occurrence for each subject.**

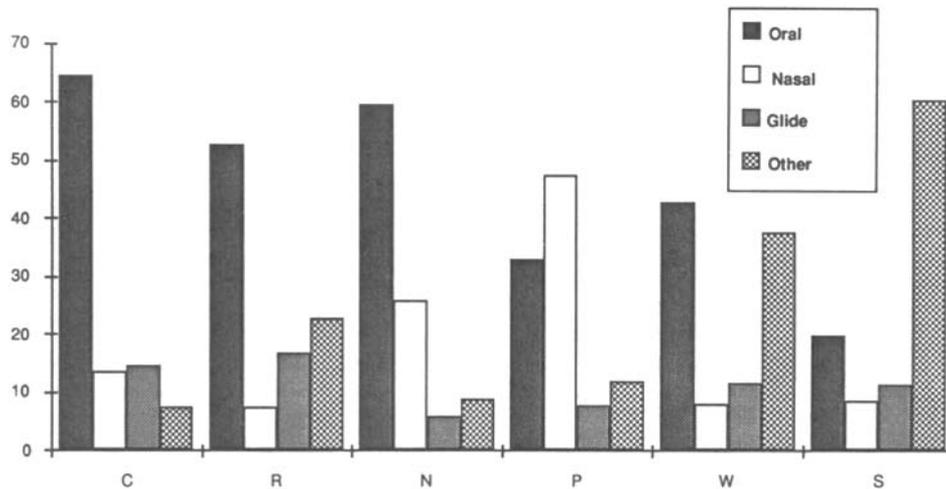


FIGURE 2. Consonant manner of articulation: percentage of occurrence for each subject.

across a variety of types. However, of the top three vowel types for the 6 subjects, all but one vowel for 1 subject (S, [v]) were mid or low front or central vowels, as would be expected from other descriptions of vowels characterizing babbling.

Group and individual trends for vowels were apparent for vowel height and front-back dimensions. Figure 3 displays each individual subject's percentages for vowels in the entire corpus characterized by height. Vowels were grouped into high ([i, I, u, v]), mid ([e, ε, Λ, ə, ɔ, o]), and low ([æ, a]) categories. Some trends resulted from this type of analysis. Midvowels were ranked top in use by 3 subjects; high vowels were most used by 3 subjects (W and S). One subject used low vowels with highest frequency. Group mean frequency for mid vowels was 40%. For both high and low vowels it was 29%. Overall group trends mirrored the individual profiles.

Figure 4 displays individual percentage of occurrence figures for vowels in the entire corpus for the front back dimension. Vowels were grouped into front ([i, I, e, ε, æ]), mid ([a, Λ, ə]), and back ([u, v, ɔ, o]) categories. The category "other" is the same as in Figure 3. These included [ε] and a few diphthongal forms. Front and central vowels account for

the largest trends in the data. Front vowels predominated in 4 subjects; central vowels in the remaining 2. Group mean frequency for front vowels was 43.4%; for central vowels, 41.7%; and for back vowels, 13.5%. Back vowels were accounted for mainly by occurrences in 2 subjects (W and S). Overall, patterns for vowels included predominant trends for mid and low front and central vowels in 4 subjects (C, R, N, P). Two subjects (W and S) employed high back vowels more frequently.

Consonant and vowel frequencies remained relatively constant during the babbling period. Results of a split-half analysis revealed no instance in which the overall frequencies for consonants in the three consonant place categories or vowels in the 9-cell vowel matrix changed in frequency by more than 5%.

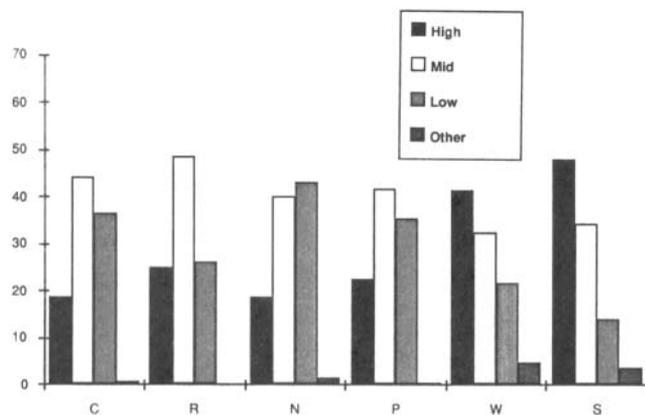
**Reliability**

The results obtained from the point-to-point method will be summarized first, to allow comparison with other studies. Reliability for consonants averaged 76.8%. Individual comparisons of pairs of transcribers on a single tape varied from 63% to 83% agreement. Only 3 of the 20 individual scores

TABLE 4. Percentage of various vowel categories (>5%) and total number of vowels produced by each subject.

		Subject											
		C		R		N		P		W		S	
Segmt.	%	Segmt.	%	Segmt.	%	Segmt.	%	Segmt.	%	Segmt.	%	Segmt.	%
[Λ]	25.8	[ə]	26.5	[a]	26.4	[æ]	23/6	[ε]	15.4	[ε]	15.9		
[a]	24.4	[ε]	19.6	[Λ]	17.6	[ə]	19.1	[a]	13.0	[v]	15.7		
[æ]	12.1	[a]	19.0	[æ]	16.7	[I]	13.5	[u]	12.4	[I]	13.2		
[I]	7.8	[I]	16.7	[ə]	14.7	[Λ]	12.5	[v]	10.6	[u]	11.8		
[I]	7.6	[æ]	7.2	[I]	11.0	[a]	11.7	[I]	10.1	[ə]	8.3		
[ə]	5.5							[æ]	8.6	[æ]	7.5		
								[I]	8.4	[I]	7.3		
								[ə]	5.8	[Λ]	6.6		
										[a]	6.6		
Total	2825		2933		2728		1516		3409				2982

Note. Overall total = 16,393.

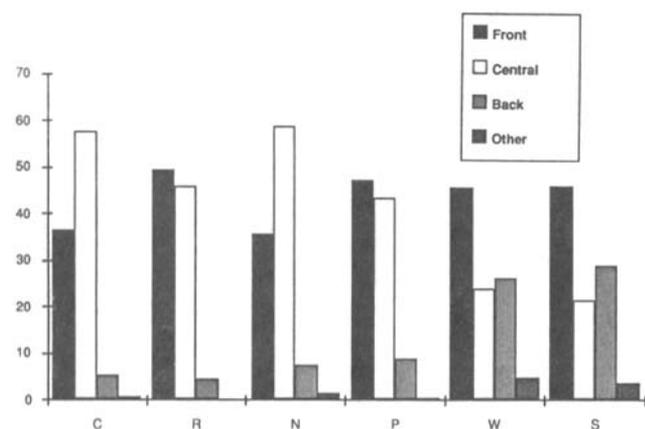


**FIGURE 3. Vowel height: percentage of occurrence for each subject.**

were below 70%. Reliability for vowels averaged 44.8%. Individual comparisons ranged from 33% to 69%.

Reliability for individual consonants varied in terms of percentages of agreement and types of disagreements. Overall, reliability was quite high for alveolar consonants ([d], 86.1%; [n], 88.3%, [j], 78.5%), considerably lower for labials ([b], 73.6%; [m], 53.2%; [w], 57.7%), and extremely low for velars ([g], 36.6%). For labials, disagreement for [b] mainly involved manner ([w, b]); disagreement for [m] mainly involved place ([n, m]); and disagreement for [w] involved both manner and place ([m, n, w]). The main disagreement for [j] involved manner but not place change ([d, j]). More instances of the primary transcriber's [g] were transcribed as [d] than as [g], ([d, g], 49%) by the other transcribers.

For individual vowels, reliability ranged from 0% for [u] (only 9 instances) to about 60% for [æ]. The average is 35.1%. This average is only a little higher than the average of the highest alternative preferences for each vowel (22.6%). Back vowels have particularly low reliability (15%). If vowels are analyzed in terms of a 9-cell matrix (i.e., high, mid, and low by front, central, and back categories), mean reliability increases to 49.9%. Pooling results across neighboring cells (excluding cells diagonal to other cells) increases reliability for all cells except [ə]; [u] and [ʊ] are 80% or better. This



**FIGURE 4. Vowel front back: percentage of occurrence for each subject.**

result indicates that with the exception of [ə] and the high back vowels, for which disagreements ranged across the board, there is relatively good agreement that a given vowel belongs within a broadly defined region of the overall vowel space. One might think roughly in terms of a region about one fourth the size of the vowel space, centered on the target vowel.

It is worth noting that for both vowels and consonants, lowest reliability was obtained for the least frequently occurring major subcategories. Thus, velar consonants accounted for only about 5% of consonants in the corpus analyzed for reliability, and back vowels only 3% of the vowels.

The five transcribers were also compared individually. For both consonants and vowels, means for all transcribers and ranges of differences across transcribers were computed. For consonant place, mean percentages transcribed for individual categories were labials (mean, 17.4%; range, 8.0%), alveolars (mean, 77.7%; range, 8.3%), and velars (mean, 5.0%; range 3.5%). For consonant manner, transcriber mean percentages transcribed for individual categories were stops (mean, 80.2%; range 10.9%), nasals (mean, 15.3%; range 10.4%), and glides (mean, 4.5%; range 3.8%).

For vowel height, mean percentages transcribed for individual categories for the five transcribers were high vowels (mean, 30.1%; range, 15.6%), mid vowels (mean, 27.7%; range 16.5%), and low vowels (mean, 42.2%; range 12.3%). For the vowel front-back dimension, mean percentages transcribed for individual categories were front vowels (mean, 69.1%; range, 16.0%), central vowels (mean, 28.0%; range 14.6%), and back vowels (mean 2.9%; range 1.7%).

## Hypotheses

**CV relationships.** Consonants used in this analysis were those described earlier. Only stops, nasals, and glides were analyzed as consonants. All CV syllables in the corpus composed of these categories were analyzed wherever they occurred in utterances. The resulting number of syllables for each subject is given on the left of Table 5. Number of syllables in individual subjects ranged from 1,187 to 2,545 and totaled 12,471. On the right side of Table 5, results for each subject are expressed in terms of the ratio of observed to expected frequencies in each cell. The expected value is 1.0. The 18 CV associations predicted from the "Frames, then Content" hypothesis occupy the diagonal of each of the six individual tables and are shown in bold face. All 18 predictions were confirmed (3 predictions for each of 6 subjects), whereas only 9 above-chance (i.e., above 1.0) co-occurrences were observed in the 36 instances in which CV associations were not predicted. This difference between the relative frequency of above-chance occurrences in cells that were predicted by the hypothesis (18/18) and those that were not predicted (9/36) was highly significant (chi square:  $p < .001$ ). For each individual column (18 in all) chi square analysis was used to compare the observed frequencies of the three CV sets with the expected frequencies. Expected frequencies for each of the three classes of vowel were derived from the overall frequency of that vowel type in the corpus. For example, if 60% of all vowels were front vowels, then 60% of all vowels in each consonant environment were

**TABLE 5. Ratio of observed to expected occurrences of labial, alveolar, and velar consonants with front, central, and back vowels.**

Subject	Vowels	Consonants		
		Alveolar	Labial	Velar
C N = 2487	Front	<b>1.37</b>	.19	1.52
	Central	.82	<b>1.43</b>	.66
	Back	.40	1.98	<b>1.06</b>
	Signif.	***	***	***
R N = 2349	Front	<b>1.07</b>	.43	1.19
	Central	.91	<b>1.76</b>	.73
	Back	1.00	.81	<b>1.21</b>
	Signif.	*	***	***
N N = 2183	Front	<b>1.45</b>	.49	.59
	Central	.77	<b>1.28</b>	1.17
	Back	1.06	.74	<b>1.75</b>
	Signif.	***	***	***
P N = 1187	Front	<b>1.24</b>	.70	.88
	Central	.76	<b>1.31</b>	1.03
	Back	.60	1.43	<b>1.80</b>
	Signif.	***	***	—
W N = 2545	Front	<b>1.25</b>	.65	.99
	Central	.85	<b>1.20</b>	.99
	Back	.67	1.43	<b>1.01</b>
	Signif.	***	***	—
S N = 1720	Front	<b>1.30</b>	.82	.90
	Central	.85	<b>1.37</b>	.93
	Back	.60	1.01	<b>1.22</b>
	Signif.	***	***	***

\* $p < .05$ \*\*\* $p < .001$ 

expected to be front vowels. All alveolar-vowel co-occurrence patterns (left columns) and all labial-central vowel co-occurrence patterns (center columns) were statistically significant beyond the .001 level except for the alveolar-vowel pattern in R, which reached the .05 level. In all of these cases the difference between the predicted cell frequency and the chance frequency for that cell was sufficient to have produced a significant chi square by itself. Only four of the six velar vowel patterns were significant, and in only two of those cases (N and S) was the frequency of the predicted relation sufficient to have produced a significant chi square in itself.

Of the 9 above-chance occurrences of CV subtypes that were not predicted by the hypothesis, 4 involved labial consonants and back vowels. This result, together with the result that the least-favored co-occurrence pattern (in fact, the largest departure from chance in any cell) is for labials with front vowels, suggesting that there may be a secondary tendency for the tongue to move back but not forward in labial environments. Four of the 5 above-chance co-occurrences that were not predicted by the hypothesis involved velar consonants. If the individual consonants that made up the labial and alveolar categories ([b], [m], and [w]; and [d], [n], and [j]) are considered separately, only 8 of 36 instances were exceptions to the predicted trends, and no single type of exception was preferred strongly by a majority of subjects.

**Variegation hypothesis.** As previously suggested by Smith, Brown-Sweeney, and Stoel-Gammon (1989) and Mitchell and Kent (1990), all of these infants show concurrent use of reduplication and variegation in canonical babbling. Table 6 displays percentages of use of reduplication for each subject. Four of the 6 infants show almost complete balance in use of reduplicated and variegated pairs. Two infants show a predominance of variegation, with little use of reduplicated syllables.

In the analysis mentioned earlier, in which the data of the study were split into two roughly equal consecutive halves, the mean percentages of reduplicated syllables increased from 35% to 43%, but this difference was not significant. Subjects were relatively consistent in use of reduplication in the two halves of the study. No subject changed by more than 16%. Three subjects showed less reduplication in the second half; the other three showed more.

Instances of syllable pairs containing the consonants and vowels selected for analysis were used to test the 12 individual predictions regarding variegation (2 predictions, 6 subjects). The number of eligible pairs of syllables for each subject is shown separately for consonants and vowels in Table 7. Chi square analysis was done separately for vowels and consonants in each individual subject. Observed frequencies were tested against frequencies expected if each vowel or consonant pair occurred only as often as expected from the frequencies of the two individual segments in the overall corpus. As the hypothesis regarding consonants involved a prediction of changes in amount of oral constriction, stops and nasals were allocated to one manner category and glides to the other. For the variegation hypothesis, all 12 individual chi square tests of the relation between observed and expected frequencies were significant beyond the .001 level in the predicted direction. Table 7 shows ratios indicating the extent to which the observed variegation instances exceeded chance (1.0) in the direction of the predictions.

It is of interest to note, in percentage terms, the number of subpatterns observed in this study that were consistent with the "Frames, then Content" hypothesis. Fifty percent of all CV syllables were of the 3 predicted types, and 50% were of the other 6 types. This was 10% above what would have been expected on the basis of the overall relative frequencies of the consonants and vowels making up the CV pairs. Eighty-four percent of all vowel pairs in variegated babbling differed in vowel height, whereas 56% were expected by chance. Sixty-one percent of instances of consonant varie-

**TABLE 6. Percentage of times in which the first syllable of a pair was followed by the same syllable (reduplication).**

Subject	Reduplication %	Total # syllables
C	46	1004
R	56	1007
N	50	822
P	51	491
W	19	1110
S	10	520

**TABLE 7. Ratio of observed to expected variegation for vowels and consonants.**

Subject	Vowels		Consonants	
	Ratio*	Total # syll. pairs	Ratio*	Total # syll. pairs
C	1.40	255	2.2	155
R	1.44	142	2.5	168
N	1.30	189	6.1	137
P	1.40	107	6.0	58
W	1.64	350	3.0	303
S	1.65	160	2.0	143
Total		1203		964

\*Chi square for every subject  $p < .001$

gation involved variegation in manner, whereas only 22% would have been expected by chance. (This low percentage is due to the relatively small number of glides in the corpus.) Overall, considerably more than half of the observed patterns conformed to the predictions of the "Frames, then Content" hypothesis, whereas only about half would have been expected by chance.

**Summary.** In terms of relative frequencies of segment types, 4 subjects were relatively typical in the tendency to favor stops, nasals, glides, and vowels in the lower left quadrant of the vowel space. Two other subjects showed strong preferences for fricatives and other vowels. All 30 predictions for both the CV co-occurrence hypothesis and the variegation hypothesis suggesting a predominant role of the frame in babbling were confirmed, most of them at a convincing level in quantitative terms. The two unusual infants were no less subject to the predicted effects than were the more typical infants. Well over half of the observed subpatterns in the study conformed to the predictions of the "Frames, then Content" hypothesis, whereas only half would have been expected by chance. Analysis, including vowels as well as consonants, confirmed a trend towards coexistence of variegated babbling and reduplicated babbling across the babbling period. Various types of reliability data were presented. Their implications will be discussed in the following section.

## Discussion

This study has provided an extremely strong confirmation of the contention that most of the articulatory variation in babbling is frame-related. Patterns of CV syllables and sequences of CVs seem to reveal this effect. Results suggest that for normally developing infants, the main source of variance in reduplicated babbling is uniform amplitude of successive cycles of oscillation of the mandible. The main source of variation in variegated babbling is nonuniform amplitude in successive cycles of oscillation of the mandible, affecting either the closing (consonantal) phase or the opening (vocalic) phase, or both. This finding suggests that even in many cases in which transcription suggests that the tongue occupies a nonresting position in the front-back dimension during a babbled utterance, even a multisyllabic one, its position may not change during the utterance. Thus,

an utterance such as [daedaedae] might only involve vertical tongue movement produced by the mandible. The forward movement required may occur before the acoustic onset of the utterance. One way to summarize the results obtained in this study is with the phrase "Frame Dominance." Results obtained offer the most specific and comprehensive answer available to the question of potential articulatory constraints in babbling.

Subjects W and S were unusual in their high levels of preference for "other" consonants and for high vowels, particularly high back vowels. However, the specific predictions of frame effects were confirmed as strongly in these subjects as in the 4 typical subjects. The existence of large numbers of otherwise normal infants with untypical vocalization patterns is often noted in the literature. Such infants are often called "loose" articulators (Menn, 1983) or "mush mouth" babies (Peters, 1977). We are not aware of any reports of systematic attempts to describe the babbling patterns of such infants. It is a testimony to the power of the frame-dominance concept that, when such descriptions are made, these infants seem to be as subject to the basic constraints subsumed by the concept as infants with more typical patterns.

The validity of these conclusions is contingent on another—that the pattern of transcriber biases observed here did not have a systematic effect on the outcome of the two main hypotheses of the study. Most of the confirmations of these predictions were at percentage levels far higher than those characterizing the differences between transcribers. In addition, in the case of CV co-occurrences, only in instances where there is a bias in the same direction in both a relevant consonantal category and the associated vowel category would there be the possibility of an artifactual result. There are only two cases in which two related categories are both biased in the same direction relative to the mean by more than 2%. These two cases involve alveolars and front vowels in P and N, but the two biases go in opposite directions. Consequently the frame-dominance phenomenon seems for the most part to transcend transcriber bias, at least with the large numbers of observations used in this study.

Conclusions can be drawn from this reliability analysis for the interpretation of the results of this study. First, it would seem that the appellations "velar consonant" and "high back vowel" are unlikely to be adequately specified by the transcription procedure, and the acoustical data seem a necessary accompaniment to a fully satisfactory account of such sounds. The second implication concerns the relative frequencies of various consonants and vowels to be reported for individual subjects. If one were to think in terms of a true value for any one of these segments for a given infant (a debatable point in itself) then one could conclude from the present analysis that it could differ by several percentage points from the value obtained by a single transcriber. Nevertheless it would appear that certain main aspects of the relative frequencies of sounds, such as those summarized in the introduction, are probably soundly based.

The variegation hypotheses involve *changes* from one consonant or vowel to the next. A bias towards or against any segmental category would have the effect of increasing the appearance of similarity between sound categories,

tending to collapse the difference between two sound categories by partially absorbing one category into the other. This would tend to spuriously reduce the amount of variation. If this occurs in the vertical dimension (across vowel height or consonant manner), it would bias results against the variegation hypotheses; however, if it occurs in the horizontal dimension (the vowel front-back dimension, or consonant place), it would bias results in favor of the hypothesis. The overall pattern of such biases seems not to favor one of these categories over the other.

The transcription-based evidence for the predicted CV co-occurrence constraints has recently been supplemented with objective evidence from an acoustical study involving 4 of the 6 subjects in the present study (Matyear, MacNeilage, & Davis, 1994). The question was considered in the case for which most of the CV syllables are relevant—relations of alveolar and labial consonants with front and central vowels. It can be assumed that if there is a tendency for transcribers to transcribe according to the hypothesis, two patterns should be observed: (a) Vowels designated as central vowels in labial environments would be, on the average, more front than vowels designated as central in alveolar environments. (b) Vowels designated as front in alveolar environments would, on the average, be more central than vowels designated as front in labial environments. The null hypothesis, indicative of an absence of bias, is that there would be no overall differences in either central or front vowels depending on the environment they are in. Formant frequencies of mid and low front and central vowels were measured in symmetrical (CVC) labial and alveolar stop consonant environments. In all cases two transcribers agreed on the identity of the vowel type. A total of 337 vowels were measured. Results are shown in Table 8.

Following accepted convention, it was assumed that a rough index of amount of tongue fronting in vowels can be provided by the height of the second formant. Counter to both the bias hypothesis and the null hypothesis, second formant frequencies of both front and central vowels are much higher in alveolar environments than in labial environments. An analysis of variance showed a main effect for consonant environment to be significant beyond the .001 level. This result suggests that transcribers are *underestimating* the extent to which the CV patterns evaluated in this study fit the “Frames, then Content” hypothesis in this particular case at least.

The least convincing confirmation of the predictions from the “Frames, then Content” hypothesis involved the relation between velars and back vowels. Ambiguity in this relation could perhaps have been expected given that the results showing transcription reliability was disturbingly low for velars among consonants and for back vowels among vowels. The ambiguity in this result needs to be resolved by acoustical study. In adult English, the tongue dorsum has been shown to be in a more anterior (palatal) place of constriction for so-called velar stops in front vowel environments than in back vowel environments (Ladefoged, 1975). Infants such as C and R, in whom a velar-back vowel effect appears to be diluted by a velar-front vowel effect, may have a more palatal place of consonant articulation in front vowel environments than in back vowel environments. This ten-

dency could be revealed in acoustical terms by a high second formant accompanying the consonants transcribed as velar in the front vowel environments. A study of this possibility is presently in progress. Acoustical study may also show that the vowels transcribed as central vowels in velar environments are produced with further back articulation than vowels transcribed the same way in alveolar and labial environments. English transcribers not familiar with unrounded back vowels may tend to transcribe such vowels as central (D. K. Oller, personal communication, May 9, 1993). It remains possible that the relation between dorsal consonants and contiguous vowels may be as subject to the constraint against rapid differentiation of tongue position as are alveolars and front vowels, but this remains to be established.

This study also provides additional evidence for recent claims of Smith, Brown-Sweeney, and Stoel-Gammon (1989) and Mitchell and Kent (1992) that variegated babbling is relatively frequent from the onset of canonical babbling. Results of this study, which considered both consonants and vowels, suggests that there may not be any change in the relative frequency of reduplicated and variegated babbling across the babbling period. The earlier claim of reduplicated and variegated babbling stages suggested a plausible progression from simple to complex. The distinction between simple and complex forms remains an attractive option. The reduplicated forms certainly seem more basic. However, the argument that variegated forms are more complex requires that the infant have the capability of producing these more complex forms at the same time as the simpler forms.

The frame-dominance concept provides a principled basis for determining exactly how an infant makes progress in speech acquisition beyond the babbling stage. Progress can be defined in terms of the extent to which the infant is escaping frame-dominance. This question can be explored quantitatively by using ratios such as those computed for the co-occurrence and variegation hypotheses.

The claim that frame dominance constraints are motor constraints should not be taken to imply that perceptual factors do not play a role in the initial form of babbling. It has been shown that infants with hearing loss do not typically begin to babble until several months after the normal onset time (Oller & Eilers, 1988) and do not exhibit normal babbling patterns. Auditory experience seems necessary for production of a normal babbling pattern on schedule. However, if babbling patterns, at least in early stages, tend to be uniform across language environments in terms of sound preferences, then auditory experience, which differs in detail across languages, cannot be responsible for the uniformity

**TABLE 8. Second formant frequencies for mid and low front and central vowels in alveolar and labial stop consonant environments.**

Vowel	Alveolar	Labial
ɛ	2676	2402
æ	2706	2399
ɔ	2107	1942
a	2440	2120

of such patterns. Consequently, it appears that motor constraints are more responsible for detailed patterns observed in early babbling than perceptual shaping influences. In particular, if there is indeed a lack of co-occurrence of labial consonants and central vowels in adult languages, the perceptual model for infants, then the presence of co-occurrence constraints in infants would strengthen the claim that there is a motor basis for these patterns.

Although it is generally conceded that motor constraints are more responsible for the limitations of infants in producing words than perceptual inabilities (e.g., Menn, 1983), there has been relatively little effort to characterize these constraints (see MacNeilage & Davis, 1993). One reason for this lack of focus is the emphasis, in studies of acquisition, on linguistic perspectives emphasizing abstract representational capabilities associated with words, with an accompanying neglect of functional considerations, especially prelinguistic functional considerations. Recent cognitively oriented perspectives, although more attuned to functional concerns, have emphasized the freedom of individual infants to choose different output patterns on nonmotor grounds (Menn, 1983; Boysson-Bardies, 1993). In the absence of an explicit characterization of motor constraints, these claims of freedom from motor constraints have remained largely unevaluated. The strength of the Frame Dominance effects shown in this study and their insensitivity to considerable individual differences in both infants and transcribers suggests that linguistic and cognitive approaches may have greatly overestimated the freedom of speech development from motor constraints.

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