Is There a "Trochaic Bias" in Early Word Learning? Evidence from Infant Production in English and French

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Studies of speech perception and segmentation in the prelinguistic period, early word production, and patterns of function word omission in early syntax have all recently emphasized the role of the trochaic accentual pattern in English, sometimes positing a universal trochaic bias. We make use of perceptual and acoustic analyses of words and babble from 9 children acquiring English and 5 acquiring French in the late single-word period (13–20 months) to provide a direct test for the existence of such a bias. Neither English nor French infant vocalizations were exclusively trochaic. The iambic productions of American infants were traced to the presence of iambic phrases in the input. Differences between English and French in the acoustic realization of accent in infant vocalizations were also traceable to adult patterns. However, the almost bipolar distribution of trochaic and iambic patterns in the data from English-learning infants was ultimately traceable to the integration of prosodic and segmental patterning in individual child word production templates, themselves arguably the product of an earlier acting articulatory filter.

INTRODUCTION

In the past 10–15 years, the fundamental role of prosody in early language acquisition has come to be clearly established. Two major lines of research have been primarily responsible for this. Fernald and her colleagues (Fernald, 1984, 1985, 1991; Fernald & Kuhl, 1987; Fernald & Mazzie, 1991; Fernald & Simon, 1984) have pursued the question of infant response to prosody in the input from the first months of life through to the early word production period, whereas Jusczyk and his colleagues (Hirsh-Pasek et al., 1987; Jusczyk et al., 1992; Jusczyk & Kemler Nelson, 1996; Kemler Nelson, Hirsh-Pasek, Jusczyk, & Wright Cassidy, 1989; Myers et al., 1996) have traced the (typically prosodic) perceptual bases of infants' growing "knowledge" or representation of their language through the first year (for reviews, see Jusczyk, 1997; Vihman, 1996). The possibility that prosodic marking of syntax in input speech may provide an important starting point to launch the child into the acquisition of grammar (Gleitman & Wanner, 1982) was debated at some length in a recent edited volume (Morgan & Demuth, 1996). However, the many-sided discussion of the likely basis for segmentation of the signal in acquisition, by scholars from a variety of different backgrounds, failed to consider the possible relevance of production to this process. In fact, studies of early word production have provided strong prima facie evidence that infants attend to speech sound patterns that are familiar from their own vocalizations. This notion, which has been termed the "articulatory filter" (Vihman, 1993), assumes that an action plan, together with the auditory and proprio-ceptive experience afforded by practice with it and the effort involved in implementing it (Elbers & Wijnen, 1992), provides an advantage to perceptual processing, rendering congruent patterns in the input flow of speech especially salient.

One theoretical construct that has been independently formulated on the basis of both perception and production data is the "trochaic bias." Jusczyk, Cutler, and Redanz (1993) have recently shown a listening preference for trochees (or strong-weak accentual pattern, e.g., *pliant*) over iambs (weak-strong: *comply*) in 9-month-olds acquiring English, although not in 6-month-olds. This bias was shown by 21 out of 24 9-month-old participants in a first experiment but by only 15 out of 24 in a second, in which the segmental patterns of the input were masked by low-pass filtering. The data provided a statistically significant group effect in both experiments but also pointed toward strong individual differences within the group. Although the majority of infants exposed to English may develop an early sensitivity or preference, presumably based on familiarity, for the trochaic rhythm that typifies most of the content words they hear, there appear to be a good many babies who fail to develop such a preference, perhaps because trochaic rhythm is not the only one they hear, as we demonstrate below.

Allen and Hawkins (1978, 1979, 1980) proposed "an overall rhythmic constraint for English speaking children, specifically that their speech tends to be trochaic" (1980, p. 242) and went on to note that "we

have so far found no particular rhythmic bias in . . . discrimination learning," which led them to argue that the bias is a constraint on speech production, not perception. Although Allen and Hawkins noted that some cross-linguistic data, especially from French, appeared to contradict the universality of the hypothesis, they nevertheless maintained that rhythmic constraints might prove to be universal and thus might derive from an underlying neuropsychological tendency. Noting the relative paucity of relevant literature, however, these authors comment that "we know with certainty only what appear to be some of the best problems to approach first. One of these, for example, would be a direct comparison of French and English children's biases in learning trochaic versus iambic disyllables. . . . The 'preferred' accent contour of words in these two languages is directly opposite, and we should be able to observe the differential effects of this bias in the young children's speech" (1980, p. 240). A word of caution, however: Allen and Hawkins neglected to note the difference in accentuation between words and phrases in English.

The strongest piece of evidence mentioned by Allen and Hawkins in support of their proposal is children's tendency to omit pretonic but not posttonic unstressed syllables. That is, the classic child form for *banana* is ['nænʌ] or ['bænʌ], not *[bə'næn], and for *potato*, ['teto] or ['peto], not *[pə'tet] (1979) (where * marks nonoccurring forms). In a study of child phonological processes in relation to sound change Vihman (1980) provided cross-linguistic support for this tendency in the form of data from 11 children (up to age 2,6) acquiring six languages (Czech, English, Estonian, German, Slovenian, and Spanish). These data strongly conform to the pattern described (85% of the initial unstressed syllables were omitted as against 24% of final unstressed syllables). In a reconsideration of these data in relation to the putative production bias toward trochees, however, Vihman (1996) suggested that the effect may relate instead to lengthening of the final syllable in adult input speech, which renders that syllable more salient to the infant; Snow (1995) has independently put forward the same suggestion.

The idea of a trochaic bias for English production has recently been revived (Gerken, 1994, 1996; see also Demuth, 1996; Echols, 1996). In an elegant series of experiments, Gerken and her colleagues (Gerken, 1991; Gerken, Landau, & Remez, 1990; Gerken & MacIntosh, 1993) have demonstrated that, in the early stages of syntactic acquisition (starting at 23 months), children learning English can be shown to selectively omit function words in imitation tasks (but not nonsense-word substitutes for function words), especially in subject position, where they form an iambic foot (or minimal prosodic unit) with the following noun or verb (*the bear; he kissed*). Gerken argues convincingly that these findings provide evidence that children have knowledge of function words before they begin to produce them. Her production data also conform to the reduction strategy described above: Pretonic unstressed syllables are far more vulnerable to loss than posttonic unstressed syllables. As Vihman (1996) suggested, the same perceptual salience account would apply (on the phrasal level) to early syntax as to long words.

Segmental aspects of phonological development have received considerably more study than prosody, but little has been learned about the process or even the timing of the integration of these two aspects (although Echols, 1993, and Schwartz & Goffman, 1995, have made some attempt to address this question). As far as segmental phonology is concerned, we have good evidence that the beginnings of phonological organization can be identified by the time a child has about a 50-word cumulative vocabulary (Vihman, 1996). In particular, we find that, by this time, children each exhibit their own preferred word production templates, involving favored word length, favored sequences of sounds, and favored word and syllable frames. Within the general constraints on early production, then, each child develops his or her own first system—but that system is also guided by phonetic and phonotactic characteristics of the child's ambient language. Thus, for example, children acquiring English tend to prefer monosyllables, whereas children acquiring French produce as many words with three or more syllables as words with only one (Vihman, Lleó, & Velleman, 1996). Table 1 provides a representative sample of word templates, or broad word production types, used in early phonological organization by three children each acquiring English and French.

To illustrate the nature of phonological system in this early period, consider just one child each from the English and French groups. Molly shows a word template (noted on the table in angle brackets next to her name) that features a medial stop (as in *apple*) or nasal (as in the child's form for *around*), followed by a vowel, typically schwa. Adaptation of adult words to her preferred word pattern is exhibited in Molly's production of *Brian,* for example, in which the segmental sequence of the adult word is overruled in favor of a disyllable in which the final nasal of the adult form serves as the pivotal medial consonant; *around, down,* and *hand* are similarly adapted to fit the familiar template, whereas *diaper* is sufficiently similar in its adult form to need little adaptation (see

Table 1   Templates in Early Phonological Organization

Participant and Template	Structural Type
English:	
Deborah <VCV>:[a]	
(a)bottle [ʔoˈbaː]	disyllable, iamb
hi [ʔəˈhaɪ]	
(a/the?)monkey [hm̩ˈmæː]	
mooooo [bɔˈhɔː]	
Molly <(C)VCə>:	
apple [ˈʔæpæ]	disyllable, trochee
around [ˈwanːə]	
Brian [ˈpanːə]	
diaper [ˈtæpʊ]	
down [ˈtaŋːə]	
hand [ˈhanːə]	
Sean <CVk>:	
monkey [mɤːk]	monosyllable
moocow [mœk]	
truck [jʌk]	
French:	
Charles <VCV>:	
au revoir 'goodbye' [aˈvwa]	di- and polysyllables,
c'est bon 'it's good' [haˈbõ]	iambic
chapeau 'hat' [haˈbo]	
chaussures 'shoes' [ɛˈʤo]	
garçon 'boy' [haˈʒœ]	
lapin 'rabbit' [aˈpa]	
poupée 'doll' [aˈpa]	
Laurent <(CV)CVlV>:	
chapeau 'hat' [bəˈlo]	
cuillère 'spoon' [koˈla]	
de l'eau 'water' [dəˈlo]	
la brosse 'the brush' [bəˈla]	
la dame là 'that lady' [lɔlədaˈla]	
Marie <(V)(CV . . .)CVCV>:	
c'est beau ça 'that's nice'	
[jibosa], [epoːtɕa],	
[eboʃa], [aːʔɔnɛboʃa],	
[ɔlebosa]	
papillon 'butterfly' [papjɪ],	
[m̩papijə], [dɛəapapinɔ],	
[wejaːpabijəpapijə]	

[a] C = supraglottal consonant, V = vowel (optionally preceded by [h] or [ʔ]; <> indicates the general form of a word production template, abstracting across word types and tokens.

Vihman & Velleman, 1989, for an account of the development of Molly's template). Of the French sample, Laurent shows a similarly "active" template, in this case involving the medial lateral [l] (Vihman, 1993). Whereas some adult forms naturally fit the model (and may have served to "inspire" its formation in the first place)—for example, *de l'eau*—others are only globally similar to the child form: Thus, *la brosse* is reordered in the child's production so that the favored medial [l] can be realized; even more radically, *chapeau* (also sometimes produced as [bobo])

is reordered to begin with a labial stop, [b], instead of the fricative [ʃ], which this child does not yet produce at all; the medial slot is filled "from the template" with the favored medial consonant [l]. We will return to the prosodic forms exhibited here in our discussion below.

The present study is designed to explore the nature and extent of knowledge and production control for prosody in children learning English and French at the point when phonological organization is emerging, to determine the status of trochees and iambs in early words and contemporaneous babble vocalizations, and to seek evidence for the status at this developmental point of the purported universal "trochaic template" in relation to both perceptual salience and possible rhythmic constraints on production.

Before going on to describe our data we will take as a reference point a simple model of the way that "biological" (or natural physiological) and "ambient language" factors might be expected to interact in the acquisition of prosodic structure in this period of initial lexical organization (see Figure 1). We limit our attention here to disyllables, for three reasons. First, these are the most prominent category of child productions across a number of languages and thus provide the largest data set for cross-linguistic analysis. Second, disyllables (unlike monosyllables) permit comparative instrumental analysis of amplitude, duration, and pitch on two prosody-bearing units (syllables) within a single production frame, an important methodological advantage. Finally, children's disyllables provide an empirical basis for evaluating the trochaic template hypothesis.

The model we are proposing assumes that the natural tendency for duration is for the second syllable to be longer than the first (final syllable lengthening characterizes a large number of languages and is found within the first 6 months of life: Delattre, 1966; Laufer, 1980; for discussion, see Vihman, 1996, chap. 8). For pitch, it assumes that a falling contour across the vocalization (i.e., with higher pitch on the first syllable) is the most natural (Kent & Murray, 1982). For amplitude, similarly, a drop over the course of an utterance has been proposed as a natural consequence of the gradual drop in subglottal pressure (Lieberman, 1986). Alternatively, it has been suggested that agreement with pitch is the natural tendency (Allen, 1983; Vaissière, 1983). These are the "biological tendencies," or initial physiological constraints.

Each adult language can be seen as presenting its particular set of prosodic challenges to the child. Where the disyllabic contour required by the adult

	Biological Tendencies	Ambient Language Effects		Predictions	
	Expect more on-	French	English	French	English
Duration	Σ 2	* Σ 2	Σ 1	Σ 2	[varies]
Pitch	Σ 1	Σ 2	* Σ 1	[varies]	Σ 1
Intensity	Σ 1 OR same as pitch	Σ 1	* Σ 1	[varies]	Σ 1

KEY:

Σ 1   First syllable

Σ 2   Second syllable

Figure 1   A model of the interaction of "biological" and "ambient language" factors in the acquisition of prosodic parameters. The model incorporates the assumption that the input for English is primarily trochaic. * = Ambient language parameter matches biological tendency: predict early acquisition. [varies] = Expect same-language-group children to differ; prosodic parameter not established.

language agrees with the biological tendency for a given parameter, the model predicts early acquisition—which means relatively stable and adult-like production by the time of our study, toward the end of the one-word period. Where the adult language differs from the biological tendency, the model predicts for this same developmental point variation across the children acquiring the language.

As Allen and Hawkins suggested, French provides a useful foil for English, given the complementary accentual characteristics of the two languages. Both languages show final syllable lengthening (Delattre, 1966), but whereas the English lexicon is largely trochaic (Cutler & Carter, 1987), French accents the second syllable of disyllables and is thus iambic (Fletcher, 1991; the term "stress" is not fully appropriate for French and will be avoided here). In fact, French accent is phrase- as well as word-final, so that a disyllabic word is iambic in final position but is not perceptibly accented elsewhere in the phrase. In English, in contrast, words are typically trochaic (74% according to Delattre, 1965), but phrases (or "sense-groups," in Delattre's terms, e.g., *with light*) are typically iambic (75% of phrases). For the sake of argument, we incorporate the lexical bias toward trochees in the prediction of ambient language effects for English in the model.

Returning to the predictions of the model then, the duration ratio characteristic of adult French (1:1.8, according to Delattre, 1966, 1:1.7 according to Wenk & Wioland, 1982) should be roughly approximated in infant vocalizations by the end of the one-word period, because the final syllable lengthening of the adult models is in accord with the natural tendency for infant production. For English, on the other hand, the same adult tendency toward final syllable lengthening—which Bernstein-Ratner (1986) finds to be exaggerated in mother's speech to infants—is counterbalanced by the dominance of trochaic words, whose initial (stressed) syllable is nearly as long as a final (unstressed) syllable. Accordingly, later acquisition of adult-like duration ratios is predicted for English, with variability across infants.

With regard to pitch, the phrase-final accent of French, together with a tendency for declarative as well as interrogative sentences to end in a rise or in relatively high pitch (Delattre, 1961), means that the second syllable should often be higher than the first in the adult model, whereas the dominant trochaic pattern of English, together with a tendency for most declarative sentences to end in a fall, should mean lower second syllable pitch. Accordingly, lower second syllable pitch could be expected to stably characterize the vocalizations of children acquiring English

in our study, whereas the French children should vary.

Finally, French accent is characterized by a drop in amplitude, creating an additional potential difficulty for children only if congruence of pitch and amplitude is taken to be the natural pattern, whereas the trochees of English should be in accordance with the "natural" pattern under either proposed interpretation, which should mean that the infants' early words would stably feature higher amplitude as well as pitch on the first syllable.

METHOD

The data used here were collected as part of three longitudinal studies of children in transition from babbling to speech, two groups acquiring American English (the Stanford study, 10 participants: Vihman, Macken, Miller, Simmons, & Miller, 1985; and the Texas study, six participants: Davis & MacNeilage, 1995) and a third group acquiring French in Paris, France (five participants: Boysson-Bardies & Vihman, 1991; Vihman, Kay, Boysson-Bardies, Durand, & Sundberg, 1994). In all three groups the families were middle class and well-educated; the mothers' ages ranged from 25 to 40. All of the infants were normally developing; all five of the Stanford children, one of the Texas children, and three of the French were firstborn. Children were recorded on a weekly or biweekly basis (for English and French, respectively) on audio only (Texas), or on audio and video (Stanford and Paris), in natural interaction at home with their mothers. For further detail regarding data collection, segmental transcription and reliability, see the papers referenced above. For this study, we used data from the five children in the Stanford study who reached the "25-word point" (defined as the first half-hour recording session in which 25 or more different identifiable word types were used spontaneously; this corresponds to approximately a 50-word cumulative vocabulary: Vihman & Miller, 1988). We also included data from four out of six children in the Texas study and all five participants of the French study.

Disyllables, including both words and nonwords or babble vocalizations, were taken from each child's 25-word point. In some instances, supplementary disyllables were selected from the session immediately preceding the 25-word point for the Stanford group. The children acquiring English in Texas were included to provide a large enough sample of instrumentally analyzable disyllables for English to allow quantitative analysis (the Stanford sample provided 136, the Texas sample 73, and the French sample 176 usable disyllables). Data regarding the participants' ages, total vocalizations, word tokens, and disyllables analyzed are given in Table 2.

Selection Criteria

Disyllables were extracted from the audiotapes and digitized to 16 bits using an Audiomedia sound board in a PowerPC (sampling rate 22.2 kHz). Utterances selected for inclusion minimally contained two

Table 2   Participants: Age at "25-Word Point," Total Vocalizations and Word Tokens

Participants	Age at 25-Word Point	Total Vocalizations (Words and Babble)	Total Word Tokens (% of All Vocalizations)	Total Disyllables Analyzed
English:				
Stanford sample:				
Deborah	1,3.24	264	97 (37)	25
Emily	1,3.21	175	113 (65)	29
Molly	1,2.20	454	384 (85)	26
Sean	1,3.23	368	152 (41)	22
Timmy	1,4.22	239	146 (61)	34
English:				
Texas sample:				
Caroline	1,1.0	273	57 (21)	16
Michael	1,5.24	423	89 (21)	20
Neddie	1,8.17	133	101 (76)	12
Ruthie	1,6.27	423	189 (55)	25
French:				
Carole	1,2.5	158	85 (54)	16
Charles	1,3.15	260	157 (60)	50
Laurent	1,5.15	238	153 (64)	37
Marie	1,7.26	446	125 (28)	37
Noël	1,5.23	297	124 (42)	36

open (vocalic) phases separated by a closed (consonantal) phase; we included every disyllable that lent itself to objective analysis by the methods available. Syllabic consonants were included as syllable nuclei. Disyllables with interfering talking or other noise were not used. Utterances judged as belonging to the intonation group of bounded words were also excluded (Cruttenden, 1986), as were utterances that showed excessive shifts from modal register, excessive vocal effort, whisper, or creaky voice. To give some sense of the weighting of criteria in the data that we were unable to use, the disyllables excluded from the half hour sessions of two participants, Emily (English) and Carole (French), are presented in Table 3. The reasons for exclusion of disyllables differed by child. For example, Carole whispered during much of the session; Emily connected many disyllables together in one intonation group (labeled "connected" in Table 3). In addition, noisy toys led to the exclusion of 21 of Carole's utterances, whereas in Emily's case the production of medial glides with no clearly traceable formant transitions rendered many utterances unsegmentable.

More than three successive repetitions of a single word type were also excluded from analysis, on the grounds that a single "prosodic set" could be inferred and such mechanical repetition—highly characteristic of some participants—would unduly bias the results. The same type reappearing later in the session was used, however. Phonetic transcriptions of the sessions were consulted for information as to word identity and segmental shape; the tokens were retranscribed as necessary on the basis of the additional acoustic information, especially as regards voicing, which is not reliably transcribable by ear alone. Word identification procedures, carried out for earlier studies of the Stanford English and French

samples, are reported in detail in Vihman and McCune (1994).

Acoustic Analysis

Utterances were analyzed for indices of fundamental frequency (F0), intensity, and duration using Soundscope speech analysis software. The measurements for each syllabic nucleus included F0 average, root-mean-squared (rms) voltage, and duration. All F0 measurements were based upon either a peak picking or autocorrelation algorithm checked against the narrow band spectrograph for accuracy. Clearly aberrant data points were eliminated.

Duration measurements were made using concurrent information from the amplitude trace, narrow and wide band spectrograph, intensity curve, and pitch contour. Additionally, screens were used to expand the time scale of the beginning and end points of each vowel around a manually placed marker. Rules for segmentation were developed based upon the consonants surrounding the vocalic nucleus (DePaolis, Vihman, & Davis, 1996). All measurements of F0 and intensity were based upon the vocalic nucleus as determined by these segmentation rules. Figure 2 illustrates the information available on the screens for segmentation.

Stress Assignment: Perception Test

Three experimenters separately judged the auditory percept of each utterance for coding into one of four categories: trochaic, iambic, even, or unassignable. In separate sessions, judgments were made of the full set of English and of French disyllables in random order at a comfortable listening level in a quiet room under earphones. Each vocalization was presented twice. A disyllable was assumed to be iambic, trochaic, or even if at least two experimenters agreed. If there was no such agreement the vocalization was judged indeterminable.

RESULTS

Descriptive statistics for the three acoustic parameters of duration, fundamental frequency, and amplitude for all the English and French utterances are presented in Table 4. The French infants produced a mean duration ratio of 1:1.62, whereas the American infants' second syllable was on average only slightly longer than the first, 1:1.20. Additionally, note that the standard deviation for duration in the English sample is considerably higher than in the French, especially on the first syllable. With respect to pitch and amplitude, the French infants showed "more" of

Table 3   Reasons for Excluding Disyllables for Two Children

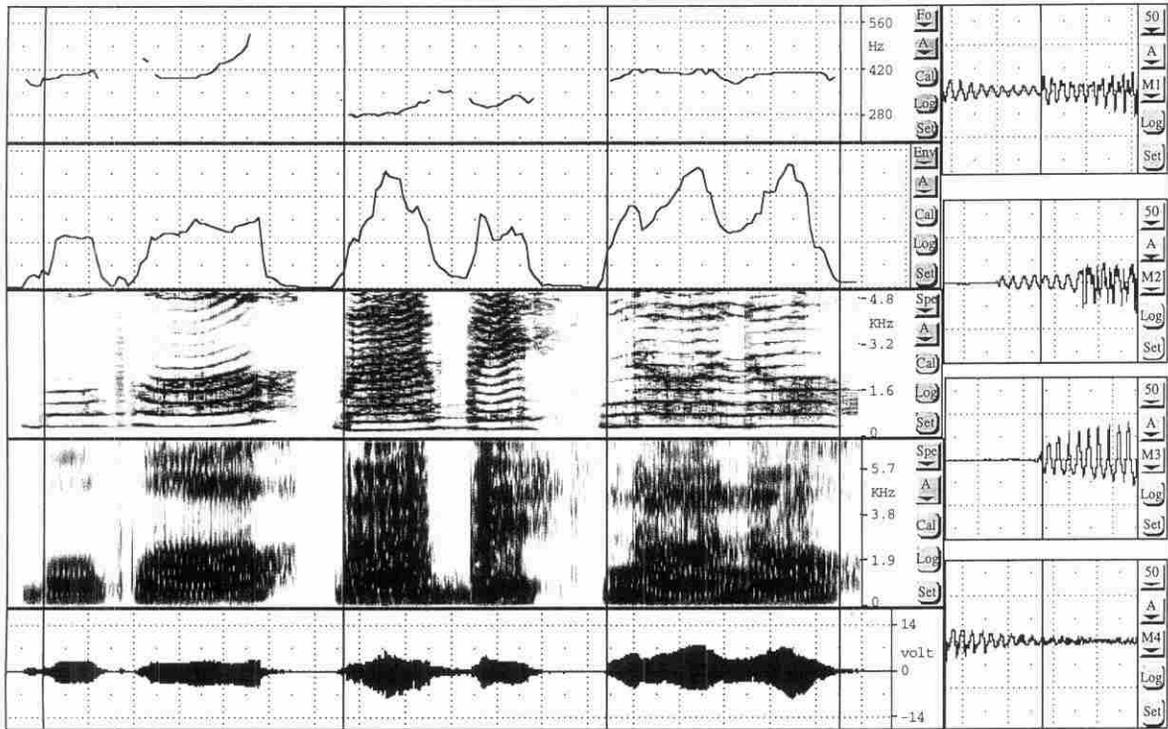| Reason	Emily	Carole
Noise	4	21
Talking	3	4
Connected	9	0
F0	1	1
Singing	2	0
Whisper	2	17
Breathy	0	3
Unsegmentable	8	3
Creak	0	2
Excited	4	1
No. unsegmentable	33	52
Total disyllables	62	68

Figure 2   Display of the Soundscope instrument used to segment the disyllables. This display shows three disyllables (from left to right: /bopa/, /babi/, and /nono/) which were judged as iambic, trochaic, and even stressed, respectively. The screen displays (from top to bottom): Fundamental frequency, amplitude envelope, narrow band spectrograph, wide band spectrograph, and the amplitude trace. The location in the amplitude trace of each of the four markers is also displayed in more detail in the four expanded time scale displays on the far right of the instrument.

both on the second syllable (1.9 semitone and 1 dB advantage for the second syllable), on average, although the standard deviations (3.6 and 4.3, respectively) reflect a high degree of variability. The English-learning infants exhibit slightly higher F0 (0.3 semitone difference) and amplitude (0.5 dB difference) on the first syllable, also with a high degree of variability as reflected in the standard deviations (3.2 and 6.1, respectively).

Table 4   Descriptive Statistics for the English (N = 209) and French (N = 176) Disyllables

	English		French	
Measure	M	SD	M	SD
Duration of vowel 1 (ms)	190	96	129	49
Duration of vowel 2 (ms)	228	125	209	92
F0 ratio (semitones)[a]	−.3	3.2	1.9	3.6
Amplitude ratio (dB)[a]	−1.5	6.1	1.1	4.3

Note: The duration ratio for English and French is 1.20 and 1.62, respectively.
[a] Positive/negative ratio indicates higher/lower amplitude or F0 on vowel 2.

To go beyond these descriptive statistics, which constitute a "bottom-up" analysis of the data, we carried out the ("top-down") perception test outlined above to determine which of the infants' vocalizations would be characterized by (native English-speaking) adult listeners as trochaic, iambic, even-stressed, or unassignable. Overall, 86% of all the children's productions (90% of the French, 83% of the English) produced an "assignable" percept of accent pattern (i.e., were labeled consistently by at least two of the three listeners); 67% of these were judged either iambic or trochaic (72% for French, 66% for English). As can be seen in Figure 3, which displays only those utterances judged either iambic or trochaic for each infant, four of five French infants produce primarily iambs. In contrast, the American infants differ in their production of iambs and trochees: Five produce predominantly trochees, three produce mainly iambs, and one produces iambs and trochees in equal proportion.

Given the relatively even division of the American infants' vocalizations into trochees (n = 77) and iambs (n = 60), it is worthwhile reconsidering the descriptive statistics separately for each of these stress
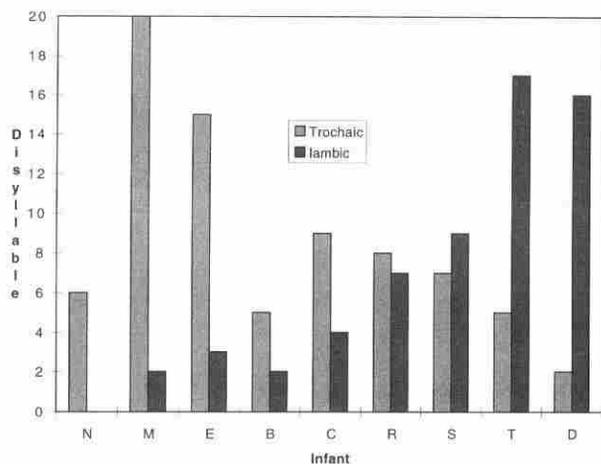
Figure 3 Iambic and trochaic production for each infant. The first nine infants are from the English sample, the last five from the French sample.

categories. The acoustic measures are in fact very different for the two categories for all three parameters in the English data (see Table 5). The duration ratio (see Table 5, note) is 1:2.04 for iambs versus 1:0.71 for trochees, the semitone difference for fundamental frequency is 1.3 for iambs (that is, higher pitch on the second syllable) versus −1.6 for trochees (an even greater difference in favor of the first syllable), and the decibel ratio for amplitude is 4.2 for iambs versus −6.1 for trochees. The French data, in contrast, show less extreme differences in duration and in amplitude; it is only the semitone differences that seem to strongly distinguish between the small number of vocalizations heard as trochees ($n = 24$) and those heard as iambs ($n = 102$).

The response variables of duration, fundamental frequency, and amplitude (each analyzed as the ratio of syllable 2 divided by syllable 1) were analyzed by generalized linear models (McCullagh & Nelder, 1989). Amplitude and fundamental frequency were analyzed assuming homogeneous variances leading to an unbalanced ANOVA, whereas duration, which exhibited a functional dependence between variance and mean, was analyzed assuming a constant coefficient of variation. Tests of significance were based on the F ratio for all three measures. The operating models for all three included more levels than in the parsimonious model presented in Table 6. A significant effect was found for language and the interaction of language and stress (plotted in Figures 4–6). Location (Texas versus Stanford) also proved significant for duration and amplitude, but closer inspection revealed that these differences, which are allowed for in the analysis, are not relevant to the issues of interest here.

The presence of a substantial number of iambs in the word and babble vocalizations of the infants acquiring English is not in accord with the predictions made by the trochaic bias hypothesis. The source of the iambs for English-learning infants may be the frequent occurrence in the input of monosyllabic words carrying the nuclear accent of the phrase and preceded by an unstressed syllable, often a function word such as an article. To ascertain the extent to

Table 5   Descriptive Statistics for the English and French Disyllables Classified in the Listening Experiment as Either Trochaic, Iambic, or Even

Measure	English			French		
	M	SD	N	M	SD	N
Trochaic:						
Duration—vowel 1 (ms)	231	107	77	135	36.8	24
Duration—vowel 2 (ms)	165	79.4	77	167	66.8	24
F0 ratio (semitones)	−1.6	3.3	77	−2.7	2.7	24
Amplitude ratio (dB)	−6.1	4.2	77	−3.3	3.2	24
Iambic:						
Duration—vowel 1 (ms)	131	69.3	60	129	53.6	102
Duration—vowel 2 (ms)	267	142.3	60	227	101.6	102
F0 ratio (semitones)	1.3	2.5	60	3.8	3.0	102
Amplitude ratio (dB)	4.2	5.8	60	3.0	4.0	102
Even:						
Duration—vowel 1 (ms)	203	81.3	36	133	51.3	32
Duration—vowel 2 (ms)	283	123.2	36	205	68.2	32
F0 ratio (semitones)	−.8	2.1	36	.2	1.9	32
Amplitude ratio (dB)	−1.4	2.7	36	−.1	2.7	32

Note: The duration ratio for iambs and trochees is, for English, .71 and 2.04, respectively, and for French, 1.24 and 1.76.

Table 6   Analysis of Variance for Response Variables Duration, Fundamental Frequency, and Amplitude

Source	df	ms	F
Language	1		
Duration		2.465	6.72*
F0		.323	26.17**
Amplitude		1.729	25.81**
Location	1		
Duration		2.698	7.36*
F0		.001	.03
Amplitude		.303	4.51*
Language × stress	4		
Duration		11.291	30.80**
F0		.202	16.38**
Amplitude		2.727	40.70**
Error A	33		
Duration		.367	. . .
F0		.012	. . .
Amplitude		.067	. . .
Error B	292		
Duration		.228	. . .
F0		.004	. . .
Amplitude		.040	. . .

Note: Error A is an estimate of the variation due to the interaction of language, stress, and child and is used to compute the *F* values. Error B is an estimate of the variation within children; since the repeated observations derived from individual children are not independent, Error B is not valid for testing purposes.
*$p < .05$; **$p < .01$.

which iambic models of this kind are actually included in the mothers' input we analyzed the speech of two of the mothers from the Stanford sample (at the time when the infants were about 12 months old), selecting for analysis the mothers of two of the infants who showed the most extreme production of trochees (Molly: 20 trochees, 2 iambs) or iambs (Deborah: 2 trochees, 18 iambs). All one- and two-syllable words falling under nuclear accent were tabulated as

Figure 5   Interaction of stress by language for amplitude. A positive ratio indicates higher amplitude on the second syllable whereas a negative ratio indicates higher amplitude on the first syllable.

iambic or trochaic or as making up part of an iambic or trochaic unit-phrase. Deborah's mother's speech included 47% iambic words or phrases (note that her 71 trochees included 23 tokens of *doggie*), whereas Molly's mother's speech included 54% iambs. The figures are quite similar, unlike the distribution of trochees and iambs in the two children's vocalizations. Of the 147 iambic patterns, 66% were monosyllabic content words preceded by a function word (mainly determiners, pronouns, and prepositions); nearly half (49%) consisted of determiner + monosyllabic noun.

To learn more about the infant vocalizations judged to be iambic in either the English or French samples we plotted the distribution of all the iambs by absolute length of unstressed initial syllables in the two languages. Whereas the majority of the unstressed syllables for both groups fell in the range 110–150 ms, the American infants also produced a sizable proportion of extra-short unstressed syllables (20% below 70 ms, versus 12% for French). Pursuing
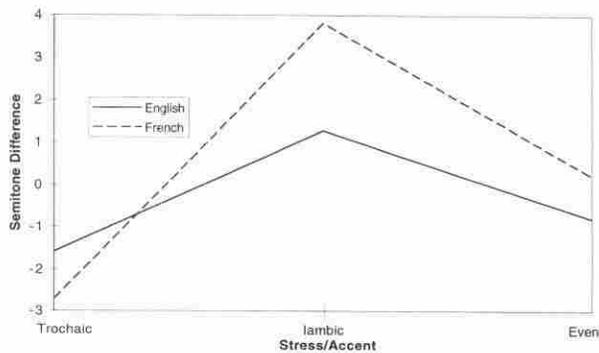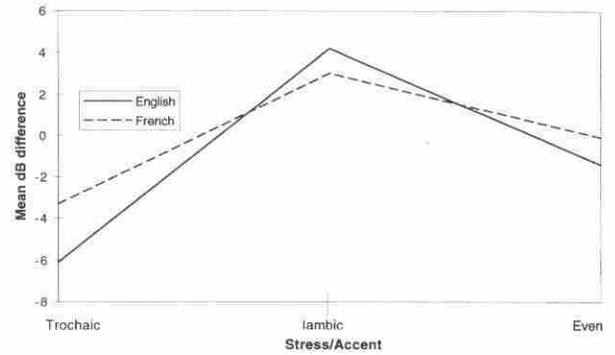

Figure 4   Interaction of stress by language for fundamental frequency. A positive ratio indicates higher F0 on the second syllable whereas a negative ratio indicates higher F0 on the first syllable.
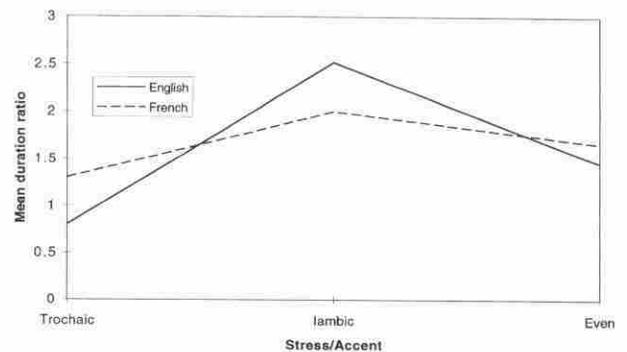

Figure 6   Interaction of stress by language for duration. A duration ratio greater than one indicates a longer second syllable.
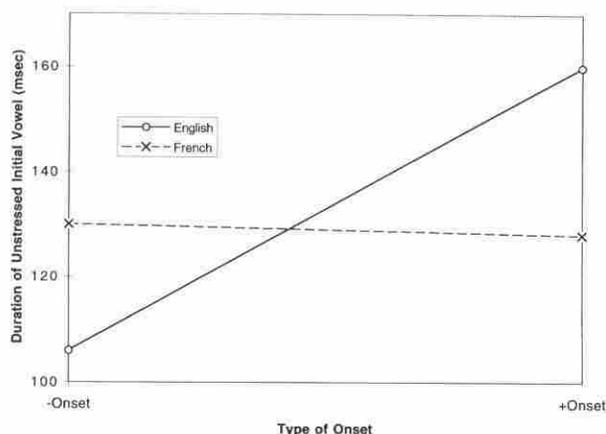
Figure 7   Interaction of onset type by language

the question of unstressed initial syllables further, we carried out a two-factor ANOVA, language × syllable type (CV [consonant, vowel] versus V) to compare the duration of unstressed initial syllabic nuclei with consonantal onset ("CV") against those without consonantal onset ("V": These included glottal, i.e., [h] or glottal stop, and null onsets). The interaction was highly significant, $F(1, 158) = 8.86$, $p = .003$. As seen in Figure 7, in English but not in French there is a striking difference in the length of initial unstressed syllables with and without a consonantal onset.

DISCUSSION

To test the model presented earlier, in which the timing of accent learning is taken to reflect the interaction of physiological tendencies with ambient language influence or guidance, we conducted both "bottom-up" and "top-down" analyses of our data. The first test of the model was based upon descriptive statistics carried out on both English and French utterances. As predicted, the duration ratios for the French infants were relatively stable and adult-like, whereas the American infants showed only slight second syllable lengthening, on average, and a considerably higher level of variability for each syllable (especially the first) than was found in the French data. The complementary predictions of variability for English in duration (where the dominant trochaic word pattern is expected to conflict with the natural tendency toward final lengthening) and of stability in French (where the accentual lengthening of the final syllable conforms to the natural tendency) were realized in the quantitative analyses of the children's productions.

With respect to pitch and amplitude, however, the English children proved to have as high a level of

variability as the French, despite the prediction that, for English, the conformity of the presumed trochaic bias of the input with the natural tendency toward a fall in both pitch and loudness or intensity should result in early accentual learning. In other words, the infants acquiring English failed to show the stability predicted by the model, which assumes exposure to homogeneous trochaic patterns from the ambient English input parallel to the French infants' exposure to homogeneous iambic patterns.

Our "top-down" analysis of the two language samples reveals the source of error in the model: Whereas the French children are, as expected, producing almost exclusively iambs (to the extent that one syllable is heard as more accented than the other, i.e., disregarding the vocalizations judged as "even"), the American children show a range of different production patterns, from wholly trochaic to largely iambic. To see whether the iambic pattern in the children's output reflects iambic patterns in the input, we can compare the duration ratios for adults for each stress type with those produced by the children. Whereas the ratio for the French adult (open syllable) iambs is about 1:1.78, the adult ratio for English iambs (unstressed nonfinal to stressed final syllable, open syllables only) is 1:2.57, a far more extreme difference (Delattre, 1966). For trochees in adult English, in contrast, the ratio of (stressed) nonfinal open syllable to (unstressed) final open syllable is 1:1.11. Here the effect of final-syllable lengthening is balanced by the effect of stress on the initial syllable. Recall that the comparable figures for the vocalizations of the infants acquiring English are 1:2.04 (iambs) and 1:0.71 (trochees)—a contrast that reflects the adult means and that has a clear source in the dual-pattern adult model (i.e., a model that includes iambs as well as trochees).

We carried out a statistical comparison of F0, amplitude, and duration in the three stress categories across the two languages. All three measures are manifested significantly differently by language. Exploring the differences shown on Table 5, it is clear that French infants showed higher F0 on the stressed syllable in iambic utterances than did the American infants. This is consistent with the French adult model, which is wholly iambic and uses F0 as an important acoustic correlate of an accented syllable. As regards duration, the American infants produced longer stressed syllables in both trochees and iambs. This most likely reflects the difference in the adult duration ratios between the two languages, noted above. In addition, for both trochees and iambs American infants produced greater differences in amplitude between stressed and unstressed syllables

than did the French infants. This may be due in part to the emphasis on loudness in American infant-directed speech (Albin & Echols, 1996).

What are we to make of the American infants' production of iambs, despite the evident trochaic bias in the lexical input? Altogether, at most 38 different adult iambic (disyllabic) models can be identified for the five Stanford children over the 7 months of the study, or 28% of the 134 identifiable targets for disyllabic productions (some of them based on monosyllabic adult forms, such as Molly's ['han:ə] for *hand,* others based on longer forms, such as Deborah's ['taɪti] for *pat-a-cake* or Timmy's variants of the form [ə'ga] for the proper name *Great Gable*). Of the iambic models, nine are ambiaccentual onomatopoeic compounds such as *num-num, quack-quack,* and *row-row,* which may be produced as either trochees or iambs or both in speech to children. Just three of the models are genuinely iambic single words in adult speech (*balloon* [used by two children], *giraffe,* and *raccoon*); in addition, both *goodbye* and *hello* are normally iambic, although both are variable in stress placement in actual usage. The largest number of iambic models (23, or 61%) consist of phrases, especially noun phrases in which the article is represented by a filler vowel in the child production.

We determined that, for the English sample but not the French, a distinct subcategory of unstressed initial syllables may be identified that lack an initial supraglottal consonant; these syllables tend to be extra short. These reduced initial syllables suggest "dummy vowels" (or "presyntactic devices": Dore, Franklin, Miller, & Ramer, 1976); they have their counterpart in adult English in pretonic reduced vowels, typically schwa (Fear, Cutler, & Butterfield, 1995, report a mean length of 78 ms for these vowels, across five sentences produced at two speaking rates by 12 participants). In contrast, French short (unaccented) syllables fail to show changes in vowel quality (Fletcher, 1991).

The American children's iambic disyllables with extra-short initial syllables give the prosodic impression of an adult phrase, especially when the stressed syllable is (in context) a recognizable attempt at a monosyllabic word, such as *a bead* [ʔə'βɪ] (Emily), *a juice* [hʌ'duis] (Sean), or *the neck* [ʔi'næ] (Timmy). We cannot rule out the possibility that some of the extra-short initial unstressed syllables in these vocalizations involve "startup vowels," reflecting articulatory constraints rather than emergent linguistic knowledge. The far smaller number of such extra-short vowels in the French infants' vocalizations suggests that it is the structure of English input speech that is the main contributing factor, however.

Where the child is reproducing a familiar phrase, the iambic pattern appears to be holistic; there is no evidence of segmentation into article + noun at this point. This is in sharp contrast to the overstressed production of function words described by Allen and Hawkins for 3-year-olds and suggests a possible U-shaped developmental profile for the representation of English phrases. Such a profile might be sketched as follows:

1. In the period immediately preceding first word production, between 9 and 12 months, when the child's attention begins to focus on native language patterns and the first word comprehension is shown, trochaic patterns are perceptually predominant for a majority of children acquiring English—but not for all. We can deduce from this that although (trochaic) words are noted by most children (based on Jusczyk et al., 1993), (iambic) phrases are also salient for some and are heard globally, as iambic patterns (*a ball*); these patterns are reproduced as such (in both words and babble) by the end of the one-word period, as reflected by the iambs that co-occur with the more common trochaic productions in our data.

2. In the middle of the second year, between the 25-word point and the first establishment of grammatical morphemes, the use of "presyntactic devices" has been identified. Peters and Menn (1993, p. 755) have shown that although many children proceed in a lexically and semantically oriented way to arrive at knowledge of morphosyntax, others build on "prosodic acoustic characteristics of the speech stream." For example, Peters and Menn's data from the child Seth showed a very gradual shift, over the age range 1,7 to 2,3, from the use of "fillers," such as schwa or a syllabic nasal, to the use of identifiable closed-class morphemes such as articles, pronouns, and prepositions. In the same developmental period other children have been reported to engage in "experiments" with dummy syllables, such as all-purpose uses of schwa or reduplicated syllables before content words (e.g., *It away* [ʔiʔ waija] or [wiwai], from Gwendolyn Stemberger, age 1,11, Stemberger, 1988).

By about age 1,11, Gerken found a "trochaic bias" in her participants' production and at the same time evidence of implicit knowledge of function words that were nevertheless not being produced with any consistency: In the imitations of article + noun that she elicited, the article tended to be omitted—a "regression" in production, in relation to the holistic production of iambic forms that we report for some children already by the end of the one-word period. In the case of both Seth and Gwendolyn, knowledge of grammatical morphemes is clearly emergent, re-

sulting in the production of ill-specified filler syllables; for these children at this stage elicited imitations of article + noun phrase, as in Gerken's experiments, would likely result in omission.

3. As the child's understanding of the function or meaning of the less salient grammatical morphemes increases along with his or her capacity to control the production of longer sequences the child will no longer omit these pretonic unstressed syllables. Instead, at this point and for an extended period of time—comparable to the long period of overgeneralization of regular past tense forms—grammatical morphemes will tend to be overstressed (Allen & Hawkins, 1980; Pollock, Brammer, & Hageman, 1993; cf. also Nittrouer, 1993, who reports overlong productions of the article *a* by 7-year-olds).

Let us now consider the role played by prosody in the development and use of templates by individual children. As shown in Figure 3, five of the American children produce substantially more trochees than iambs. The segmental production template of one of those children, Molly, was described earlier (see Table 1); this template, with its typical use of schwa in the posttonic syllable, is clearly trochaic. Such a template undoubtedly reflects attention to single disyllabic words in the input; it is likely that, once established, it also "attracts" or provides the child with a usable match for additional single word targets, given the heavily trochaic lexical input. Accordingly, the establishment of a phonological template is one (generally neglected) factor in rapid lexical growth (Vihman, Velleman, & McCune, 1994).

The English-learning children whose disyllabic vocalizations are dominated by trochees appear to be following the "word-oriented" strategy described by Peters and Menn (1993, p. 745), as (like Menn's son Daniel) they "pay . . . attention to the 'vertical' segmental information contained in single (usually stressed) syllables, focusing on the details of their consonants and vowels." Note also that, for children focusing on single words, the unstressed (posttonic) syllable of trochees will tend to be relatively well represented early on (i.e., by the end of the one-word production period) as a consequence of the greater perceptual salience afforded by final syllable lengthening in the input. The unstressed (pretonic) syllable of iambic phrases, in contrast, will tend to be poorly represented.

The disyllables of another child, Sean, whose production is dominated by monosyllables (see Table 1), include a balanced mixture of iambic words, compounds, and phrases whose first syllable is a default vowel or CV syllable (e.g., *get down*, produced repeatedly as variants of ⟨(d)adá⟩, e.g., [ʔæt'dæ], as he sat high on an antique barber chair in the family living room). Finally, Deborah produces iambic compounds and phrases, reducing disyllabic nouns to monosyllables preceded by a filler vowel in accordance with an iambic template—*bottle* [ʔo'baː], *monkey* [hm̩'mæː], *what's this* [ʔɛ'si]—but attempts no iambic single words. The same child made use of jargon-like extensions in earlier sessions (see Vihman & Miller, 1988), suggesting that (like Seth) she has been paying attention to poorly represented (pretonic) elements of the signal beyond the familiar words she produces. In summary, the individual children's favored word production templates reflect their particular sensitivities and proclivities but also constitute a first step in the integration of segmental phonology and prosody.

CONCLUSION

We began with a simple model of the potential interaction of natural physiological tendencies and ambient language guidance, somewhat arbitrarily setting the end of the one-word stage (operationalized here as the "25-word point") as a testing point. The model satisfactorily predicted relatively early attainment of adult-like duration ratios for iambs in French. Once the assumption of trochaic input in English was replaced by recognition of the dual-pattern trochaic lexical and iambic phrasal input, the duration ratios of the English-learning children proved to be adult-like as well. However, the model's predictions regarding variability across participants for duration in English and for pitch and amplitude in French could not receive a satisfactory test in groups of children that were small and of unequal sizes for the two languages. Furthermore, the maturational factor, which may affect pitch and duration differently (as claimed by Snow & Stoel-Gammon, 1994, for example), is not tested in our analyses, which lack a longitudinal dimension in this study.

Analysis of the American children's disyllabic word targets as well as of accented disyllables in the input of two of their mothers confirmed that whereas the lexical input is largely trochaic, the mothers' speech includes an equally large proportion of iambic phrases. Of the disyllabic productions that afford a reliable percept of stress in the data from the American children, only 56% are trochaic. The relatively low proportion of perceptually identifiable trochees in the children's disyllabic vocalizations is plausibly related to the presence of iambic phrases in the input.

To satisfactorily account for the relatively sharp, almost bipolar distribution of the children's productions of trochaic versus iambic patterns, however, we must go beyond biological and ambient language fac-

tors to consider the children's differing approaches or learning strategies. The production data include a substantial proportion of iambs both because the input includes iambic phrases to the same extent as trochaic words and because each child tends to filter the input through the templates he or she has developed (Vihman, 1993). The templates themselves must be taken to reflect differences in the children's attention to the input. Whereas some children focus on the detail of individual word patterns, other children have noted iambic phrases and are attempting to reproduce them holistically. Finally, given the overwhelmingly iambic pattern of the early words of French children and the sizable proportion of iambs in the production of children exposed to English, we conclude that there is little evidence of a trochaic bias (in either perception or production) that would operate above and beyond the children's individual attentional strategies and word-production templates developed under the specific influence of the language they are hearing and attempting to reproduce.

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ADDRESSES AND AFFILIATIONS

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