Allophonic and Phonemic Contrasts in Infants' Learning of Sound Patterns

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French-learning 11-month-old and English-learning 11- and 4-month-old infants were familiarized with consonant–vowel–consonant syllables in which the final consonants were dependent on whether the preceding vowel was oral or nasal. Oral and nasal vowels are present in the ambient language of all participants, but vowel nasality is phonemic (contrastive) in French and allophonic (noncontrastive) in English. After familiarization, infants heard novel syllables that either followed or violated the familiarized patterns. French-learning 11-month-olds and English-learning 4-month-olds displayed a reliable pattern of preference demonstrating learning and generalization of the patterns, while English-learning 11-month-olds oriented equally to syllables following and violating the familiarized patterns. The results are consistent with an experience-driven reduction of attention to allophonic contrasts by as early as 11 months, which influences phonotactic learning.

Languages contain both contrastive (phonemes) and noncontrastive sounds (e.g., allophones). Whether a specific phonetic difference is contrastive or not varies across languages such that a contrastive difference in one language can be noncontrastive in another. For example, in French vowel nasality is phonemic; oral and nasal vowels may occur in the same context, creating minimal word pairs that differ in vowel nasality (e.g., "bas" [bæ] *low* and "banc" [bæ̃] *bench*).[1] Conversely, vowel nasality is not contrastive in English but determined by the phonological context. Within a syllable, vowels are nasalized only before nasal consonants and are oral elsewhere (e.g., "band" as [bæ̃nd], but "bad" as [bæd]); thus, no two English words differ solely in vowel nasality (e.g., Cohn, 1990; Kahn, 1980; Malécot, 1960; Ruhlen, 1973).

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[1]We use /æ/ to transcribe the vowel used here because this vowel is what our speaker and other listeners reported hearing. In addition, there is evidence (e.g., Escudero & Polka, 2003) that the perceived vowel is /ae/ rather than /a/.

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Initially, infants discriminate many contrasts that are not phonemic in their language. For example, English-learning 2-month-olds discriminate allophonic variants (e.g., /t/ in "night rate" versus "nitrate"; Hohne & Jusczyk, 1994). Despite this early sensitivity, infants eventually tune to their native language, for example by learning not to attend to certain contrasts. While 6- to 8-month-olds readily discriminate between nonnative consonants, 10- to 12-month-olds and adults fail to do so (e.g., Goto, 1971; Iverson et al., 2003; Kuhl et al., 2006; Tsushima et al., 1994; Werker & Tees, 1984). Similarly, infants seem to learn to ignore nonnative vowel contrasts by about 6 months of age (Cheour et al., 1998; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Polka & Werker, 1994). Thus, infants show reduced sensitivity to most nonnative contrasts, which is not surprising since they probably have little experience with sounds not present in their language.

However, not all nonphonemic contrasts are nonnative; allophonic contrasts (contrasts consisting of variants of a phoneme that do not alter the meaning of a word when exchanged) are present systematically in the input. Therefore, a learner must eventually produce allophonic contrasts reliably even though variation along the contrast is not used to distinguish between words. How then do native speakers process sounds that form allophonic contrasts? Being segments of different phonemes is not sufficient for sounds to be discriminable (e.g., [t⁼], the unaspirated /t/ that occurs after /s/, and [ḓ], the voiceless /d/, although from different phonemic categories in English, /t/ and /d/, are difficult to discriminate due to acoustic similarity; Pegg & Werker, 1997); nevertheless, adults generally process phonemic contrasts more efficiently than allophonic ones. For example, adults generally exhibit poorer and slower discrimination between allophones of the same phoneme than between two different phonemes (Boomershine, Hall, Hume, & Johnson, 2008; Whalen, Best, & Irwin, 1997).

Thus, phonemic status in the ambient language influences discrimination, but less is known about the role of phonemic status in phonological learning. In the current experiments we ask how phonological learning is influenced by infants' tuning to their language. In particular, to examine the functional relevance of a contrast's status, we looked at phonotactic learning (as opposed to discrimination), a stringent test for the loss of attention to allophonic contrasts since discrimination could be accomplished by auditory, rather than phonological, means (Pisoni, 1973).

Each language possesses naturally occurring phonotactics, or patterns involving the position and sequencing of sounds, which describe restrictions on the contexts in which sounds occur. For example, English syllables may begin or end with /st/ (e.g., "stack", "cast"), and end but not begin with /ts/ (e.g., "cats"). Infants and adults are sensitive to native-language phonotactics (e.g., Flege & Wang, 1989; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994; Mattys & Jusczyk, 2001; Mattys, Jusczyk, Luce, & Morgan, 1999; Pitt & McQueen, 1998; Vitevitch & Luce, 1999), and novel phonotactic patterns can be rapidly learned from auditory experience by infants and adults (e.g., Chambers, Onishi, & Fisher, 2003; Onishi, Chambers, & Fisher, 2002; Seidl & Buckley, 2005). However, in all cases the patterns that were assessed involved phonemes, segments that are both present and contrastive in the ambient language.

Therefore, questions remain about whether constraints involving segments that are present in the ambient language, but are not contrastive, are functionally relevant. Specifically, given that allophonic contrasts are processed less efficiently than phonemic ones by adults, infants tuned to their language may find learning easier when novel phonotactic patterns depend upon phonemic,

rather than allophonic, contrasts. On the other hand, younger infants who are not fully tuned to the sounds of their language might learn novel phonotactic patterns regardless of phonemic status.

We tested infants' learning and generalization of novel phonotactic patterns involving vowel nasality in two populations, French-learning and English-learning. Nasal and oral vowels are present in the linguistic environment of all the infants, but the contrast is phonemic in French and allophonic in English. Do French-learning (Experiment 1) and English-learning (Experiment 2) 11-month-olds learn and generalize novel phonotactic patterns restricted by oral and nasal vowels? Are English-learning 4-month-olds (Experiment 3), who are still learning the phonemic inventory of their language, affected by the phonemic status of a contrast in a phonotactic learning task?

EXPERIMENT 1

French-learning infants were exposed to syllables in which oral vowels were followed by stop consonants *and* nasal vowels by fricative consonants, or the reverse. To assess abstract learning, we tested infants with syllables containing new vowels, unused during familiarization, but varying along the same nasality contrast.

Method

Participants.   We tested 18 French-learning, healthy, term 11-month-olds ($M=11,3$; range: 10,17 – 11,18) from a Canadian city with a majority francophone population, whose language exposure was at least 80% French by parental report (8 males). Data from 18 additional infants were excluded due to fussiness (8),[2] short looking times (less than 1 s on any trial; 5), inattentiveness (2), moving off camera (2), or experimenter error (1). Parental consent was obtained for all participants in this and the following experiments.

Design and stimuli.   The stimuli were consonant–vowel–consonant (CVC) syllables constructed from six consonants and eight vowels (see Appendix for list). The initial segment was any of six consonants. The vowel was either oral /æ,ɔ,œ/ or nasal /æ̃,ɔ̃,œ̃/ during familiarization, and oral /ɛ/ or nasal /ɛ̃/ in test. The final consonant was restricted by vowel nasality to the stops /p,d,k/ or the fricatives /v,z,ʃ/. Infants were assigned to one of two pattern groups. Half were familiarized with patterns such that in every syllable the vowel, if oral, was followed by a stop consonant *and* the vowel, if nasal, was followed by a fricative (Oral–Stop group); the others were familiarized with the reverse patterns, such that in every syllable the vowel, if oral, was followed by a fricative *and* the vowel, if nasal, was followed by a stop (Oral–Fricative group). Each infant heard four test trials; half followed the oral–stop, and half the oral–fricative patterns. Syllables that were legal (followed the assigned patterns) for infants in the Oral–Stop group were illegal (violated the assigned patterns) for infants in the Oral–Fricative group, and vice versa.

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[2]We believe the high rate of fussy infants was due to temperature regulation difficulties in a newly installed testing booth.

Familiarization, with an average total duration of 197.1 s (range: 194.0 to 199.8 s), consisted of 5 blocks of syllables, each block containing a different random order of 24 syllables displaying the assigned patterns. Each test item, with a total average duration of 28.3 s (range: 26.1 to 30.6 s), consisted of three repetitions of a string of six syllables. Pauses between syllables in familiarization and in test were approximately 1 s.

Stimuli were recorded by a college-aged female native speaker of French and English. To produce the oral and nasal vowels systematically, she produced French vowels.[3] Stimuli were normalized to a consistent amplitude.

Procedure and apparatus.   Infants were tested using the Headturn Preference Procedure (Jusczyk & Aslin, 1995; Kemler Nelson et al., 1995; Seidl & Cristià, 2008). The infant was seated on a caregiver's lap in a small room with lights on the front and side walls and an audio speaker behind each side light. Each trial began with the front light flashing to attract the infant's attention. After the infant oriented toward it, the light was extinguished and one of the two side lights began flashing. Looking time was recorded when the infant maintained orientation within 30 degrees of the flashing light after an initial 90-degree headturn toward it. Total looking time did not include time orienting away, although during orientations away shorter than 2 consecutive seconds, the sounds and flashing continued.

Familiarization sounds were presented continuously and simultaneously from both side speakers. They were initiated by the first orientation toward the first flashing side light and terminated after all 120 syllables had been presented. Thus, during familiarization lights but not sounds were contingent on the infant's head orientation. Test sounds were presented from the single side speaker behind whichever side light was flashing on that trial. Each of the four test trials was initiated as in familiarization and terminated when (a) the 18 syllables had been presented or (b) the infant oriented away from the light for more than 2 consecutive seconds. Thus, during test both lights and sounds were contingent on the infant's head orientation.

Results and Discussion

Preliminary analyses including sex and pattern group (Oral–Stop, Oral–Fricative) for each experiment revealed no main effects or interactions with sex, $Fs < 2.99$, $ps > .09$, or pattern group, $Fs < 3.20$, $ps > .08$; thus, we collapsed over these factors in remaining analyses.

There was a main effect of trial type (Legal, Illegal), $F(1,17) = 10.44$, $p < .006$, in a one-way repeated measures analysis of variance (ANOVA), resulting from longer looking for illegal than legal novel syllables (see Table 1). Fourteen infants showed this pattern, $p < .005$, by a Wilcoxon rank-sign test. These results suggest that French-learning infants, for whom vowel nasality is phonemic, learned the phonotactic patterns based on vowel nasality since they generalized the patterns to transfer vowels varying along that contrast.

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[3]Acoustic measurements of a randomly selected 50% of vowel tokens used in the experiments demonstrated that, although they were produced as French, in the F1-F2 space, they overlapped with the vowels of the English participants (Midland dialect).

TABLE 1
Mean (Standard Deviation) Looking Time in Seconds, by Trial Type Across Infants in
Different Phonemic Contrast Groups, Age Groups, and Vowel Conditions

				Trial Type	
Experiment	*Contrast*	*Age Group*	*Vowel Condition*	*Legal*	*Illegal*
1	phonemic	11 months	transfer	5.0 (3.4)	10.3 (5.8)
2	allophonic	11 months	training	11.0 (5.9)	9.6 (6.5)
			transfer	8.2 (6.4)	8.0 (5.4)
3		4 months	training	15.8 (8.3)	11.6 (6.9)
			transfer	13.1 (7.1)	10.4 (8.5)

EXPERIMENT 2

Studies with allophones have generally focused on how they are produced, perceived, and used to segment speech, but not on how allophonic contrasts affect learning. We know, for example, that there are acoustic differences between the way in which segments are produced when they are contrastive in a language as opposed to when they are noncontrastive in a language (Chen, 1997); that adults generally show poorer discrimination for allophonic than phonemic contrasts (Boomershine et al., 2008; Whalen et al., 1997); and that infants and adults can use naturally occurring allophones to find word boundaries (Jusczyk, Hohne, & Bauman, 1999; Nakatani & Dukes, 1977). What is not yet known is whether allophonic contrasts are recruited during phonotactic learning.

Eleven-month-olds already know much about the phonemic inventory of the ambient language (Kuhl et al., 1992; Werker & Desjardins, 1995; Werker & Tees, 1984), having a harder time discriminating contrasts that do not occur systematically in their language; however, it is not clear how this knowledge influences later learning. Can infants still make use of a contrast when a sound is present in the input but is not phonemic? We assessed, in 11-month-old English-exposed infants, generalization of familiarized phonotactic patterns to novel transfer vowels (transfer-vowel condition) as in Experiment 1 and, in addition, we tested a separate group of infants on syllables containing the same vowels as used in familiarization (training-vowel condition), a test of learning that is potentially more sensitive than the one used in Experiment 1.

Method

Participants.   We tested 36 English-learning, healthy, term 11-month-olds ($M = 11,1$; range: 10,14–11,19) from a Midwestern U.S. town, whose exposure to English was at least 90% by parental report (19 males). Other language exposure was limited to languages in which vowel nasality is not phonemic (e.g., up to 10% exposure to Spanish or Hungarian, but not Marathi or French, was accepted). Data from nine additional infants were excluded due to fussiness (3) or short looking times (6).

Design and stimuli.   The design and stimuli were as in Experiment 1 except that there were two testing conditions: a training-vowel condition involving novel syllables containing the same vowels as used in familiarization (new in Experiment 2), and a transfer-vowel condition involving syllables containing new transfer vowels never presented during familiarization (as in Experiment 1). The infants in both conditions of Experiment 2 received the same familiarization as infants in Experiment 1.

Procedure and apparatus.   Procedure and apparatus were as in Experiment 1 except that testing occurred in the United States.

Results and Discussion

There were no main effects or interactions in an ANOVA with trial type (Legal, Illegal) as a within-subjects factor and condition (Training-Vowel, Transfer-Vowel) as a between-subjects factor, $Fs(1,34) < 1.82$, $ps > .18$ (see Table 1). Only 21 infants showed a familiarity preference (11 in the training-vowel and 10 in the transfer-vowel condition), $p > .32$, by a Wilcoxon test. The nonreliable effect of trial type was confirmed separately for infants in the training-vowel and transfer-vowel groups, $Fs < 1$. Thus, while French-exposed 11-month-olds learned and extended phonotactic patterns in which vowel nasality restricted the following consonant, English-exposed 11-month-olds failed to show either learning of the patterns with training vowels or generalization to transfer vowels.

EXPERIMENT 3

If the failure to learn and generalize the patterns in Experiment 2 arose because 11-month-old English-learning infants have learned, through tuning, to reduce their attention to vowel nasality, then younger infants, who are not fully tuned to the ambient language, may succeed in using an allophonic contrast when learning new phonotactic patterns. To explore this possibility, we tested 4-month-old English-learning infants using the same design and procedure as in Experiment 2.

Method

Participants.   We tested 36 4-month-olds ($M = 4,11$; range: 4,1–4,30) from the same population as Experiment 2 (20 males). Data from 17 additional infants were excluded due to fussiness (7), inattentiveness (2), or short looking times (8).

Design, stimuli, procedure, and apparatus.   The design, stimuli, procedure, and apparatus were as in Experiment 2.

Results and Discussion

Analyses as in Experiment 2 revealed a main effect of trial type (Legal, Illegal), $F(1,34) = 12.44$, $p < .002$, but no other reliable effects, $Fs < 1$ (see Table 1). Twenty-six infants showed

a familiarity preference, $p < .002$. The reliable effect of trial type was confirmed separately for training vowels, $F(1,17) = 7.48$, $p < .02$, and transfer vowels, $F(1,17) = 4.96$, $p < .04$. Thus, like the French-exposed infants in Experiment 1, the 4-month-old English-exposed infants in Experiment 3 learned and generalized the phonotactic patterns restricted by vowel nasality. This suggests that as infants are becoming tuned to the phonemic inventory of their language between 4 and 11 months, their propensity to rapidly learn novel phonotactic patterns based on allophonic contrasts decreases. The preference reversal between Experiments 1 and 3 (i.e., listening longer to illegal than legal syllables in Experiment 1 but longer to legal than illegal syllables in Experiment 3) is consistent with a tendency for older infants to show novelty and younger infants familiarity preferences with the same materials and procedure (e.g., Houston-Price & Nakai, 2004; Hunter & Ames, 1988).

GENERAL DISCUSSION

French-learning 11-month-old infants generalized novel phonotactic patterns to new oral and nasal vowels, whereas 11-month-old English learners showed no evidence of either learning or generalizing the same patterns. English-learning 4-month-olds, not yet tuned to the sound inventory of their language, seemed to have no difficulty either learning or generalizing the same patterns even though they were based on a contrast that is allophonic in the ambient language. These results are consistent with the hypothesis that reduced sensitivity to allophonic contrasts, as a result of tuning to the ambient language, constrains phonotactic learning. The constraint on learning imposed by allophonic status is particularly striking because allophones, unlike other noncontrastive sounds, such as nonnative sounds, occur both systematically and frequently. Corpora counts found that in French nasal vowels had a frequency of about 14.7% (VoCoLex; Dufour, Peereman, Pallier, & Radeau, 2002), while in English the frequency of vowels followed by a nasal consonant within the same syllable (a conservative estimate of nasal vowels) was in fact (slightly) higher, about 15.5% (CELEX; Baayen, Piepenbrock, & Gulikers, 1995). Thus, failure to learn novel patterns involving vowel nasality cannot be due only to lack of exposure to nasal vowels.

What, then, is the mechanism by which allophonic status constrains learning? There are at least three possible mechanisms that might account for English 11-month-olds' failure to learn the phonotactic patterns. A first possibility is that reduced sensitivity to allophonic differences results in diminished attention to variation along allophonic contrasts. Learners would fail to discriminate between oral and nasal vowels, and consequently fail to learn the new phonotactic patterns depending on that variation. However, we know that 1- to 4-month-old English-learning infants discriminate oral and nasal vowels (Trehub, 1976) and that the 4-month-olds in Experiment 3 treated oral and nasal vowels as functionally distinct. In addition, adults discriminate oral and nasal vowels whether vowel nasality is phonemic or allophonic although performance differs with phonemic status (Beddor & Krakow, 1999; Beddor & Strange, 1982). Furthermore, under some circumstances monolingual English-speaking adults can learn novel phonotactic patterns that depend on treating oral and nasal vowels differently (Bernard, Onishi, & Seidl, submitted). Thus, unless the 11-month-olds are in the dip of a u-shaped developmental trajectory for the discrimination of oral and nasal vowels (a trajectory for which we have no evidence), it seems probable that they are able to discriminate the sounds (as are the 1- to 4-month-olds and

the adults). Given the current results, we might also want to infer that unlike the 4-month-olds, the 11-month-olds have become more tuned to the ambient language and are demonstrating reduced attention to variation along the oral–nasal vowel contrast.

Second, since allophones, by definition, occur in restricted, predictable environments, novel patterns based on allophonic rather than phonemic variation are more likely to contradict preexisting native language phonotactics. Indeed, while the current patterns to be learned further restricted the permissible environments for oral and nasal vowels in French, they sometimes violated the phonotactics of English, since in English nasal vowels must be followed by nasal consonants within a syllable. Thus, the task for the French- and English-learning infants was different. French-learning infants were presented with phonemic variation in patterns that further constrained the phonotactics of their ambient language, while English-learning infants were presented with allophonic variation in which half the syllables violated the phonotactics of the ambient language, perhaps increasing task difficulty but nonetheless showing knowledge of the ambient phonotactic regularitites.

Third, although the presented syllables were CVC, it is possible that the English-learning 11-month-olds perceived an epenthetic nasal, e.g., [bæ̃nd] instead of [bæ̃d] as adults might (see Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999, for an example involving the perception of epenthetic vowels). If so, it is possible that the 11-month-olds failed to learn the patterns because there were two different syllable structures (CVC, CVNC). However, given that the actual syllables were CVC, even the perception of an epenthetic nasal consonant would demonstrate the influence of having acquired the phonotactics of English and would differentiate between the 4- and 11-month-old English-learning infants.

Our current data do not allow us to determine whether the influence of allophonic status on vowel nasality occurred only through loss of attention, through conflict with preexisting phonotactics, or due to these vowels being reinterpreted as a more complex sequence of sounds. Nonetheless, we can conclude that the differences between French- and English-learning 11-month-olds are a result of their language exposure.

The current experiments demonstrate not only that phonemic and allophonic contrasts have differential consequences for learning, even before minimal pairs are acquired, but also that sound sequences can be learned and even generalized along a featural dimension by infants as young as 4 months of age. This is remarkable since these infants are among the youngest to demonstrate such learning. Since there is little evidence that infants at this age possess phonemic categories at all, perhaps the younger infants are using a different mechanism for learning than older infants and adults; they could, for example exploit acoustic cue distributions independent of phonemes (Cristià & Seidl, 2008). In addition, the fact that both the younger English learners and the 11-month-old French learners learned the patterns is particularly interesting, since sensitivity to syllable-final phonotactics in the ambient language is found rather late in development (e.g., Zamuner, 2006).

We demonstrated learning of novel phonotactic patterns restricting final consonants from a featural class (stop or fricative) based on vowels varying along a different featural dimension (oral or nasal). Thus, our results show phonotactic learning in young infants, learning of phonotactic patterns that depend on a featural contrast as well as generalization along that contrast to segments never attested in the patterns. These results are consistent with a developmental decline in sensitivity to allophonic contrasts that arises from language exposure and that affects which sound patterns are easily learned, demonstrating, in the domain of language, how learning may constrain subsequent learning.

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APPENDIX

COUNTERBALANCING								

Familiarization		Test							
		Training vowel sets						Transfer vowels sets	
		set1	set2	set3	set4	set5	set6	set7	set8
assigned patterns:		Oral-stop	Oral-fricative	Oral-stop	Oral-fricative	Oral-stop	Oral-fricative	Oral-stop	Oral-fricative
set1	Oral-stop	.	.	legal	illegal	.	.	legal	illegal
set2	Oral-fricative	.	.	illegal	legal	.	.	illegal	legal
set3	Oral-stop	.	.	.	.	legal	illegal	legal	illegal
set4	Oral-fricative	.	.	.	.	illegal	legal	illegal	legal
set5	Oral-stop	legal	illegal	.	.	.	.	legal	illegal
set6	Oral-fricative	illegal	legal	.	.	.	.	illegal	legal

STIMULUS LISTS								

set1	set2	set3	set4	set5	set6	set7	set8
dœ̃v	dœv	dɔk	dɔ̃k	dæp	dæ̃p	dɛ̃z	dɛz
ʃæ̃v	ʃæv	ʃæk	ʃæ̃k	ʃœp	ʃœ̃p	ʃɛ̃z	ʃɛz
kœp	kœ̃p	kœ̃z	kœz	kœd	kœ̃d	kɛ̃ʃ	kɛʃ
pɔd	pɔ̃d	pɔ̃ʃ	pɔʃ	pæ̃v	pæv	pɛk	pɛ̃k
vɔp	vɔ̃p	væ̃z	væz	vɔd	vɔ̃d	vɛ̃ʃ	vɛʃ
zæd	zæ̃d	zœ̃ʃ	zœʃ	zɔ̃v	zɔv	zɛk	zɛ̃k
dæ̃z	dæz	dœ̃v	dœv	dɔk	dɔ̃k	dɛp	dɛ̃p
ʃɔ̃z	ʃɔz	ʃɔ̃v	ʃɔv	ʃɔk	ʃɔ̃k	ʃɛp	ʃɛ̃p
kœ̃ʃ	kœʃ	kæp	kæ̃p	kæ̃z	kæz	kɛd	kɛ̃d
pœk	pœ̃k	pœd	pœ̃d	pœ̃ʃ	pœʃ	pɛ̃v	pɛv
væ̃ʃ	væʃ	vœp	vœ̃p	vɔ̃z	vɔz	vɛd	vɛ̃d
zɔk	zɔ̃k	zɔd	zɔ̃d	zæ̃ʃ	zæʃ	zɛ̃v	zɛv
dɔp	dɔ̃p	dɔ̃z	dɔz	dɔ̃v	dɔv	dɛk	dɛ̃k
ʃæp	ʃæ̃p	ʃœ̃z	ʃœz	ʃœ̃v	ʃœv	ʃɛk	ʃɛ̃k
kæd	kæ̃d	kæ̃ʃ	kæʃ	kɔp	kɔ̃p	kɛ̃z	kɛz
pɔ̃v	pɔv	pæk	pæ̃k	pæd	pæ̃d	pɛ̃ʃ	pɛʃ
vœd	vœ̃d	vɔ̃ʃ	vɔʃ	væp	væ̃p	vɛ̃z	vɛz
zœ̃v	zœv	zœk	zœ̃k	zœd	zœ̃d	zɛ̃ʃ	zɛʃ
dæk	dæ̃k	dœp	dœ̃p	dœ̃z	dœz	dɛ̃v	dɛv
ʃœk	ʃœ̃k	ʃɔp	ʃɔ̃p	ʃæ̃z	ʃæz	ʃɛ̃v	ʃɛv
kɔ̃z	kɔz	kɔd	kɔ̃d	kɔ̃ʃ	kɔʃ	kɛp	kɛ̃p
pæ̃ʃ	pæʃ	pœ̃v	pœv	pɔk	pɔ̃k	pɛd	pɛ̃d
vœz	vœ̃z	væd	væ̃d	vœ̃ʃ	vœʃ	vɛp	vɛ̃p
zɔ̃ʃ	zɔʃ	zæ̃v	zæv	zæk	zæ̃k	zɛd	zɛ̃d

Counterbalancing (Upper section of Appendix)

There were two groups of assigned patterns: oral–stop, consisting of syllables in which oral vowels were followed by stops *and* nasal vowels were followed by fricatives, and oral–fricative, consisting of syllables in which oral vowels were followed by fricatives *and* nasal vowels were followed by stops. Each set followed one of the two patterns oral–stop or oral–fricative.

For familiarization, each infant was assigned to one of sets 1 through 6 (see column 1 of the Counterbalancing section). Each familiarization set was paired with two test sets that also contained training vowels and two test sets that contained transfer vowels (see row 1 of Counterbalancing section). Each infant was assigned the two transfer-vowel or the two training-vowel sets associated with his or her familiarization. Thus, for each infant, one test set contained legal and one contained illegal syllables.

For example, infant A, in the training-vowel condition of Experiment 2, would be familiarized with set1 (see row 1) and tested on set3 (legal) and set4 (illegal). Infant B, in Experiment 1 or in the transfer-vowel condition of Experiment 2, would be familiarized with the same set but tested on set7 (legal) and set8 (illegal). Infants C and D would be familiarized with set2 (see row 2) and tested on the same sets as infants A and B, but set3 and set7 would be illegal and set4 and set8 would be legal. Thus, across infants, each of sets 1 through 6, and thus every training-vowel syllable occurs as a familiarization syllable, and syllables from all sets occur equally often as legal and illegal test items.

Stimulus Lists (Lower section of Appendix)

The 24 syllables of each of the eight sets are presented in the lower section of the Appendix. Sets that instantiated the oral–stop patterns contained oral vowels followed by stop consonants *and* nasals followed by fricatives; sets that instantiated the oral–fricative patterns contained orals followed by fricatives *and* nasals followed by stops.

Familiarization: Each infant was assigned one set during familiarization, and the infant heard all 24 syllables presented five times in different random orders.

Test: Each infant was assigned two sets for test. Each set was divided into four subsets of six syllables (see divisions in Stimulus Lists). Each subset of six syllables made one of the test strings (see text). Each set thus contained four potential test strings. In each test trial, infants were presented with one test string, which was repeated a maximum of three times. As each infant received only four test trials (two legal and two illegal), each infant received only 2 of the 4 potential strings from each of their assigned test sets. Across infants, each syllable occurred as both a legal and an illegal test item.

For example, infant A (described in the Counterbalancing section) would hear the 24 syllables of set1 (column 1 of Stimulus Lists section) five times each in different random orders. Infant A was then tested on 2 of the 4 subsets of set3 (legal training-vowel syllables) and 2 of the 4 subsets of set4 (illegal training-vowel syllables). Infant B would be assigned the same familiarization but be tested on 2 of the 4 subsets from set7 (legal transfer-vowel syllables) and 2 of the 4 subsets from set8 (illegal transfer-vowel syllables). Infants C and D would be familiarized with the 24 syllables from set2 (column 2) and tested on 2 subsets from set3 and set4 (infant C) or set7 and set8 (infant D).