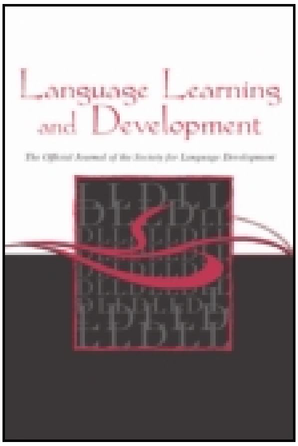

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Representations for Phonotactic Learning in Infancy

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Representations for Phonotactic Learning in Infancy

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Infants rapidly learn novel phonotactic constraints from brief listening experience. Four experiments explored the nature of the representations underlying this learning. 16.5- and 10.5-month-old infants heard training syllables in which particular consonants were restricted to particular syllable positions (*first-order* constraints) or to syllable positions depending on the identity of the adjacent vowel (*second-order* constraints). Later, in a headturn listening-preference task, infants were presented with new syllables that either followed the experimental constraints or violated them. Infants at both ages learned first- and second-order constraints on consonant position (Experiments 1 and 2) but found second-order constraints more difficult to learn (Experiment 2). Infants also spontaneously generalized first-order constraints to syllables containing a new, transfer vowel; they did so whether the transfer vowel was similar to the familiarization vowels (Experiment 3), or dissimilar from them (Experiment 4). These findings suggest that infants recruit representations of individuated segments during phonological learning. Furthermore, like adults, they represent phonological sequences in a flexible manner that allows them to detect patterns at multiple levels of phonological analysis.

Each language has phonotactic constraints that govern the permissible sequences of consonants and vowels in that language (e.g., Cruttenden, 2001). The consonant /ŋ/ (at the end of *sing*) and the consonant cluster /tv/ never appear in onset (i.e., syllable-initial) position in English, though they can in other languages (e.g., Thai has /ŋ/ onsets and Czech has /tv/ onsets). In addition, among permissible sequences of phonemes some are more likely than others; such patterns can be described as probabilistic phonotactic constraints (e.g., Frisch, Pierrehumbert, & Broe, 2004; Kessler & Treiman, 1997; Lee & Goldrick, 2008). For example, some consonants that are permissible in both onset and coda (i.e., syllable-final) positions in English nonetheless appear more frequently in onset than coda position (e.g., /b, ʃ) or in coda than onset position (e.g., /d, n, t/; Kessler & Treiman, 1997).

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Sensitivity to native-language phonotactics appears in the first year of life (e.g., Friederici & Wessels, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994), and implicit knowledge of both categorical and probabilistic phonotactic constraints guides language processing in adults (e.g., Brown & Hildum, 1956; Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999; Massaro & Cohen, 1983; McQueen, 1998; Vitevitch & Luce, 1998). Phonotactic constraints can be viewed as part of the knowledge that renders native-language speech sequences partially predictable, and thus helps make speech processing fast and accurate.

Phonotactic knowledge is language specific and reflects probabilistic variation, suggesting that phonotactic learning results from ongoing experience with phonological sequences (Dell, Reed, Adams, & Meyer, 2000; Frisch et al., 2004; Lee & Goldrick, 2008; Onishi, Chambers, & Fisher, 2002). On this view, each listening or speaking experience adds information to the phonological processing system, fine-tuning the system's ability to identify or produce similar sequences in the future. This information accumulates to permit rapid adaptation to new phonotactic constraints, which in turn influence language processing. Consistent with this view, experimental evidence shows that infants and adults rapidly learn new phonotactic constraints from brief experience (e.g., Chambers, Onishi, & Fisher, 2003, 2010; Dell et al., 2000; Finley & Badecker, 2009; Goldrick, 2004; Onishi et al., 2002; Saffran & Thiessen, 2003).

REPRESENTATIONS FOR PHONOTACTIC LEARNING

Evidence that the phonological processing system continually adapts to new phonotactic patterns raises questions about how the system represents these constraints. We and others have argued that phonotactic learning requires flexibility in analyzing phonological sequences (e.g., Fisher, Church, & Chambers, 2004; Pierrehumbert, 2001) due to the diversity of phonotactic patterns found within natural languages.

To illustrate, some phonotactic constraints apply to individual segments. In English, the constraint that /ŋ/ is never an onset is best described as applying only to this consonant because featurally similar consonants can be onsets, including other nasals (/n, m/) and other velars (/g, k/). In contrast, other constraints apply to sets of segments such as featurally defined classes (e.g., Moreton, 2002). For example, in German, word-final consonants are devoiced. This might be stated as a constraint ruling out (or devoicing) word-final voiced consonants.

In addition, some phonotactic constraints can be considered first-order constraints in that they depend on no aspect of the linguistic context other than the segment (or feature-based class) itself and its position. The illegality of /ŋ/ onsets in English is an example of a first-order constraint. In contrast, other constraints can be considered second-order constraints in that a segment's position depends on another aspect of the context. For example, in English the segments /t/ and /l/ occur in onset clusters (*trip, flit*), but never together (**tlip*), even though /tl/ clusters appear in other positions in English words (e.g., *nightlight* or *little*).

This diversity in phonotactic patterns demands flexibility in the encoding and analysis of phonological sequences. Listeners must represent speech sounds flexibly enough to learn about the behavior of individual segments as well as of featurally defined classes of segments. Similarly, whereas to learn first-order constraints listeners must generalize across the diverse contexts in which the constrained sounds appear, to learn second-order constraints listeners must retain information about the context. As discussed in the next section, infants have demonstrated some of the flexibility needed to detect these diverse patterns.

EXPERIMENTAL INVESTIGATIONS OF INFANT PHONOTACTIC LEARNING

Young infants can quickly learn first-order phonotactic constraints when the constraints apply to featurally organized classes rather than to individual segments (e.g., Cristià & Seidl, 2008; Saffran & Thiessen, 2003; Seidl & Buckley, 2005; see also Jusczyk, Goodman, & Baumann, 1999). For example, Saffran and Thiessen (2003) familiarized 9-month-olds with two-syllable stimuli that either began with voiced consonants (/b, d, g/) and ended with unvoiced consonants (/p, t, k/) or demonstrated the reverse pattern. Infants' listening times in a headturn listening-preference test showed discrimination of new items that followed these constraints (*legal* items) from those that violated them (*illegal* items). However, infants failed to discriminate legal from illegal items if the familiarization materials were reorganized to create arbitrary groupings of constrained consonants (e.g., /p, d, k/ onsets and /b, t, g/ codas).

Infants can also learn second-order constraints that are defined in terms of feature-based classes. Eleven- and 4-month-old infants learned that nasal vowels were followed by fricative consonants (e.g., /f, z/), and oral vowels were followed by stop consonants (e.g., /p, d/, or the reverse pattern; Seidl, Cristià, Bernard, & Onishi, 2009). Infants were able to generalize this pattern to syllables containing vowels not presented in familiarization, showing that they learned the pattern at the level of the feature class (nasal vs. oral vowels).

Thus, there is ample evidence that young infants can learn new first- and second-order phonotactic constraints as long as those constraints are defined at the level of the feature class (e.g., nasal vowels, stop consonants, voiced consonants). However, older infants can learn segment-based constraints. Chambers et al. (2003) familiarized 16.5-month-olds with consonant-vowel-consonant (CVC) syllables (e.g., *ban, bis, tip*) in which particular consonants were artificially restricted to particular syllable positions (e.g., /b, k, m, f, t/ were onsets; /p, g, n, s, tʃ were codas). In a headturn listening-preference test, infants discriminated new legal syllables (e.g., *bip*) from illegal syllables (e.g., *pib*). Thus, 16.5-month-olds quickly learned new first-order constraints on the syllable positions of particular consonants, even though the two groups of constrained consonants were chosen so that they could not be differentiated by a single phonetic feature or set of features.

CURRENT EXPERIMENTS

In the present work, we further explore the role of the segment in phonotactic learning during infancy; we do so in two ways. First, we ask whether there are circumstances under which younger infants can learn first- and second-order phonotactic constraints on the positions of individual consonants (as opposed to feature classes). Second, we explore how infants represent first-order versus second-order phonotactic constraints. Do infants quickly learn abstract segment-based constraints such as */f/ is an onset*, or do they instead tend to learn restrictions on consonant position that are limited to the contexts in which those consonants appeared?

One possible account of the learning of both first- and second-order phonotactic constraints would appeal primarily to representations of individuated consonant and vowel units (segments) disentangled from their adjacent contexts and linked with particular syllable positions. On this account, first- and second-order constraints would be represented differently: A first-order constraint could be described as a simple relationship between a consonant and a syllable position (e.g., /f/ is an onset), whereas a second-order constraint would require conditioning that relationship on another aspect of the phonological context (/f/ is an onset if the vowel is /I/). Another possible account would appeal primarily to representations of sequences larger than a single phoneme (e.g., Sumner & Samuel, 2007; Vitevitch & Luce, 1999). The priming of CV and VC sequences could account for the learning of constraints that can be described as first- or second-order. In essence, rather than learning that /f/ is an onset (i.e., /f/ precedes *any* vowel), participants would learn that /f/ precedes the specific vowels experienced in training (e.g., learning that both /fI/ and /fæ/ are likely biphones). On this account, first- and second-order constraints would be represented in much the same way.

If representations of individuated segments contribute substantially to rapid phonotactic learning in infancy, then two predictions follow. One is that infants should find it easier to learn first- than second-order constraints. To the extent that infants find it natural to represent and generalize phonotactic patterns at the level of the segment, independent of the local context, this should make it difficult to learn new patterns that depend on that context (e.g., Warker & Dell, 2006). In contrast, if representations of individuated segments play little role in phonotactic learning, then first- and second-order constraints should be equally easy to learn because both would depend primarily on context-sensitive representations.

The second prediction is that infants should readily generalize first-order constraints to new contexts. For example, if infants learn from brief experience that /f/ is an onset and /s/ is a coda, this learning should be extended to syllables that contain vowels not presented during familiarization. In contrast, if phonotactic learning in infancy is dominated by more context-sensitive representations, the context information in these representations should reduce infants' ability to generalize newly learned first-order constraints to new contexts.

We exposed 16.5- and 10.5-month-olds to novel first- and second-order phonotactic constraints that required keeping track of the syllable positions of individual consonants rather than featurally defined classes. Experiment 1 established that 10.5-month-olds, like 16.5-month-olds, can learn segment-based first-order constraints. Then, to test the first prediction, Experiment 2 asked whether, and how readily, 10.5- and 16.5-month-olds can learn segment-based second-order constraints. To test the second prediction, Experiments 3 and 4 asked whether 10.5- and 16.5-month-olds spontaneously generalize new first-order constraints to new vowels.

EXPERIMENT 1

In Experiment 1, 10.5-month-old infants listened to syllables in which sets of consonants were artificially restricted to onset or coda position, with assignment of consonants to positions counterbalanced across infants. The infants later heard test trials composed of syllables not presented during familiarization. *Legal* test items followed the experimental constraints, whereas *illegal* items violated them. If infants could detect the phonotactic patterns in the familiarization phase and generalize them to novel syllables, they should discriminate legal from illegal items.

Method

Participants

Sixteen healthy term 10.5-month-old infants[1] ($M = 10.3$; Range: 9.6−11.0; 4 female) participated. All infants were native English learners. Four infants were randomly assigned to each of four counterbalanced familiarization and test list combinations (see below). An additional 2 infants were tested but not included because they cried.

Materials

The key manipulation involved the restriction of consonants to particular syllable positions in CVC syllables, counterbalanced across infants. We used a subset of the syllables recorded for previous experiments with 16.5-month-olds (Chambers et al., 2003); the syllables were recorded in a sound-attenuated booth by a female native English speaker. Two sets of four consonants that could not be differentiated by a single phonetic feature or collection of features (set 1: /b, k, n, f/; set 2: /p, g, m, s/) were combined with the vowels /æ/ and /I/ to create two master lists of 32 syllables each, displaying opposing first-order constraints on consonant position. In one master list, set 1 consonants were onsets and set 2 consonants were codas (e.g., /bæp, bIp/); in the other master list, set 2 consonants were onsets and set 1 consonants were codas (e.g., /pæb, pIb/). Each master list was divided in half, creating four sublists of 16 syllables each, with the eight consonants and two vowels equally divided between them. One vulgar word was replaced by repeating a syllable within its sublist.[2]

During familiarization, participants heard one of the four sublists of 16 syllables, repeated five times in different random orders with a one-second pause between syllables (approximate duration two minutes). This familiarization served to establish the experimental constraints.

During the test phase, infants heard two new sublists of syllables. The sublist from the same master list as the familiarization sublist provided novel syllables for legal test trials; one of the two sublists from the opposing master list provided novel syllables for illegal test items. Sublists were combined such that the illegal test syllables were the reverse of the familiarization syllables; thus an infant who heard /bæp/ in familiarization would hear /bIp/ (legal) and /pæb/ (illegal)

[1]One infant who met our criteria for prematurity was inadvertently included. Excluding this infant did not change the results.

[2]Some syllables used in these experiments are English words for adults. Specifically, in Experiment 1, 31% of the syllables were words. In subsequent experiments, the percentages were 42% (Experiment 2: 16.5 mos), 45% (Experiment 2: 10.5 mos), 26% (Experiment 3), and 22% (Experiment 4). Since each test trial could contain both words and nonwords, we were unable to test for effects of lexical status. However, in previous experiments on adult phonotactic learning in perception (Chambers et al., 2010; Onishi et al., 2002), lexical status has not been found to influence phonotactic learning; this suggests that when the task does not require lexical access, lexical status does not strongly govern performance (e.g., Mirman, McClelland, Holt, & Magnuson, 2008).

during test. Across infants, each sublist, and therefore each syllable, appeared in every part of the design (i.e., familiarization, legal test, illegal test).

The two test sublists were used to create eight test strings, four legal and four illegal, each comprising four unique syllables. Across the four syllables in each test string, all eight consonants and both vowels were presented, eliminating segment differences between the legal and illegal test trials. Syllables within test strings were separated by one-second pauses. Syllable order within each test string was randomly generated and fixed, with the constraint that the first syllable of each test string began with a different consonant. Each test trial consisted of up to four repetitions of one of these four-syllable strings (maximum duration about 24 seconds). Test trial orders were randomly generated with the constraints that the first two trials included a legal and an illegal trial, and no more than two trials of the same type occurred in a row. The same numbers of legal and illegal trials were presented from the left and right loudspeakers. Half of the infants experienced a legal trial first, and half experienced an illegal trial first.

Apparatus

The experiment was conducted in a dimly lit three-sided testing booth with white-curtained walls. A green light protruded from the front curtain and red lights protruded from the side curtains, at infant eye level. Beneath each side light, a loudspeaker was concealed behind the curtains. A hidden centrally located video camera allowed a coder in another room to watch the infant without hearing the stimuli and indicate to a computer the timing and direction of infant headturns. An experimenter accompanied the parent and infant into the testing room and remained concealed behind the booth's curtains during the experiment.

Procedure

Each infant sat on a parent's lap in the center of the testing booth. The parent and experimenter wore earplugs and aviation-style headphones presenting masking music.

During *familiarization*, the familiarization list played continuously from both speakers simultaneously, not contingent on the infant's behavior. The apparatus lights were used to teach the infant the headturn contingencies. A training "trial" began with the center light flashing. When the infant looked toward the light, it was extinguished and a side light started flashing. After the infant made a criterion headturn of at least 30° toward the light, it continued flashing until the infant turned away for two consecutive seconds, ending the trial. The next trial then began with the flashing of the center light. The familiarization phase ended when the entire familiarization list had been presented.

Next, during the *distracter phase*, the experimenter entered the testing booth and entertained the infant with a puppet for one minute.

Finally, in the *test phase*, each test trial proceeded as described for familiarization except that the syllables played from only one speaker at a time, and stimulus presentation (both lights and sounds) was contingent on the infant's headturns. When the infant made a criterion headturn toward the flashing side light, syllables began to play from the speaker on that side. The syllables continued to play, and the light to flash, until the infant turned away for two consecutive seconds or until the four-syllable test string played four times. The listening time for each trial was calculated as the time the infant spent orienting toward the flashing side light; intervals during which the infant turned away but turned back before two seconds had elapsed were not included. The eight test trials were presented in this fashion, and mean listening times were calculated for legal and illegal trials.

To assess reliability, all infants' headturns were re-coded from silent videotape. Primary and reliability coders' times were within 750 milliseconds of each other on 78% of trials. Eight trials (6%) were treated as missing because the infant never made a criterion headturn. Each infant contributed at least two legal and two illegal trials to the analyses.

RESULTS AND DISCUSSION

The 10.5-month-old infants discriminated between legal and illegal syllables, listening reliably longer to illegal (M = 7.38 s, SE = .94) than to legal test items (M = 5.63 s, SE = .77; $t(15) = 2.67$, $p = .017$, cohen's $d = .69$). A nonparametric analysis confirmed the difference; 12 of the 16 infants listened longer during illegal than legal trials (Wilcoxon $Z = 2.38$, $p = .017$).

These results show that 10.5-month-old infants, like older infants (Chambers et al., 2003), readily learned segment-based phonotactic patterns and generalized them to new syllables during test. They did so even though the constraints applied to individual segments and were not supported by featural similarity among the consonants subject to the same constraint. The present results also showed the same direction of preference found with the older infants, a preference for illegal syllables, when trained on first-order consonant-position constraints.

Why did infants succeed in learning segment-based phonotactic constraints at 10.5 months, when 9-month-olds failed to do so in Saffran and Thiessen's (2003) task? One possibility is simply that the infants were slightly older. Between about 7.5 and 10.5 months of age, infants' speech processing improves. For example, they become better able to identify words despite variability in speaker's voice or vocal affect (e.g., Houston & Jusczyk, 2000; Singh, Morgan, & White, 2004). Another possibility is that the tasks were different. Unlike the current study, their experiment included an opportunity to segment words before the test phase. In addition, their familiarization materials consisted of two-syllable nonsense words (*dakdot*) rather than single syllables. Any added difficulty in perceiving speech segments in bisyllables could have made it harder for the 9-month-old infants to gather evidence about the distribution of consonants from a brief familiarization phase (Jusczyk, Jusczyk, Kennedy, Schomberg, & Koenig, 1995).

EXPERIMENT 2

Experiment 2 asked whether 16.5- and 10.5-month-old infants can also learn new second-order phonotactic constraints defined over segments. Infants were familiarized with constraints in which consonant position was contingent on the vowel in each syllable (e.g., /b/ is an onset if the vowel is /æ/, but a coda if the vowel is /I/). These second-order constraints were modeled on patterns successfully learned by adults in perception (Onishi et al., 2002) and production tasks (Dell et al., 2000; Warker & Dell, 2006).

In order to compare second-order and first-order learning, we minimized differences between experiments involving participants of the same age. For the 16.5-month-olds, we used the same syllables previously used to demonstrate first-order learning (Chambers et al., 2003), reorganized to create second-order constraints, and as in that study, we recruited two groups of eight 16.5-month-old infants. For the 10.5-month-olds, we tested the same number of infants and adapted the materials used in Experiment 1 of the current paper.

Method

Participants

Thirty-two healthy term infants participated, sixteen 16.5-month-old infants assigned to one of two groups (group 1: $M = 16.3$; Range: 15.9−17.0; 4 female; group 2: $M = 16.4$; Range: 15.6−17.0; 4 female) and sixteen 10.5-month-old infants ($M = 10.2$; Range: 9.7−11.0; 8 female). All infants were native English learners. Infants in each age group were randomly assigned to one of four counterbalanced familiarization and test list combinations (see below). An additional 17 infants were tested but not included because they cried (eleven 16.5-month-olds, two 10.5-month-olds), were distracted (one 16.5-month-old), were very active (two 10.5-month-olds), or fell asleep (one 16.5-month-old).

Materials

The key manipulation involved the restriction of consonants in CVC syllables to particular syllable positions, depending on the adjacent vowel. These restrictions were counterbalanced across infants.

For the 16.5-month-olds, we reorganized the syllables used in previous experiments with 16.5-month-olds (Chambers et al., 2003) to create second-order constraints. Two sets of five consonants that could not be differentiated by a single phonetic feature or collection of features (set 1: /b, k, m, f, t/; set 2: /p, g, n, s, tʃ) were combined with the vowels /æ/ and /I/ to create two master lists of 50 syllables, each reflecting opposing vowel-contingent consonant-position constraints. In one master list, set 1 consonants were onsets if the vowel was /æ/ and codas if the vowel was /I/, and set 2 consonants were onsets if the vowel was /I/ and codas if the vowel was /æ/ (e.g., /bæp/, /pIb/). In the other master list these constraints were reversed (e.g., /pæb/, /bIp/). Each master list was divided into two sublists with each consonant equally represented in each sublist, and the two vowels approximately evenly divided across sublists. Two vulgar words were excluded; thus two of the four sublists contained only 24 syllables while the other two contained 25.

For the 10.5-month-olds, we used the syllables from Experiment 1, rearranged to create second-order constraints. Two sets of four consonants (set 1: /b, k, m, f/; set 2: /p, g, n, s/[3])

[3]Due to a programming error, the set assignment of /m/ and /n/ differed from Experiment 1 (set 1: /b, k, n, f/; set 2: /p, g, m, s/). The consonant assignment in Experiment 1 was arrived at to minimize the within set similarity of consonants. This consonant assignment was mistakenly not applied to the second-order materials for 10.5-month-olds in Experiment 2. Notice that this difference between the experiments would, if anything, make it easier for infants to learn

that could not be differentiated by a single phonetic feature were combined with the vowels /æ/ and /I/ to create two master lists of 32 syllables each, each with opposing second-order constraints on consonant position, as described above for the 16.5-month-olds. One vulgar word was replaced by repeating a similar syllable within one of the sublists.

All participants were familiarized with one sublist and tested on two new sublists, one legal and one illegal. As in Experiment 1, sublists were combined so that the illegal test syllables were the reverse of the familiarization syllables.

For both age groups, the structure and presentation of the familiarization and test phases were as described in Experiment 1; however, for the 16.5-month-olds certain differences followed from the larger number of constrained consonants. Specifically, for the 16.5-month-olds the familiarization phase lasted approximately 3 min 10 s, each test string contained 5 syllables, and there were 10 test trials with each test trial consisting of up to 3 repetitions of one of the 5-syllable test strings (maximum duration about 23 s). Test trial orders were randomly generated with the same constraints described for Experiment 1.

Apparatus and Procedure

The apparatus and procedure were as described for Experiment 1. To assess reliability, all infants' headturns were re-coded from silent videotape.

Primary and reliability coders' times for the 16.5-month-olds were within 750 milliseconds of each other on 87% of trials for the first group of infants, and 81% of trials for the second. Across the two groups of 16.5-month-olds, 6 trials (4% of trials) were treated as missing because the infant failed to make a criterion headturn (4) or was out of camera view (2). Each 16.5-month-old contributed at least four legal and four illegal trials to the analysis.

Primary and reliability coders' times for the 10.5-month-olds were within 750 milliseconds of each other on 78% of trials. Four trials (3%) were treated as missing because the infant never made a criterion headturn (3) or because of an equipment malfunction (1). Each 10.5-month-old contributed at least two legal and two illegal trials to the analyses.

RESULTS AND DISCUSSION

The 16.5-month-old infants discriminated between legal and illegal syllables, listening longer to legal (group 1: $M = 7.12$, $SE = 1.11$; group 2: $M = 8.83$, $SE = 1.10$) than to illegal test items (group 1: $M = 4.99$, $SE = .68$; group 2: $M = 5.35$, $SE = 1.06$). Listening times were reliably longer during legal than illegal trials for both groups of infants (group 1: $t(7) = 2.92$, $p = .02$, $d = 1.10$; group 2: $t(7) = 2.79$, $p = .03$, $d = 1.05$). Nonparametric analyses confirmed these differences. All 8 infants in group 1 (Wilcoxon $Z = 2.52$, $p = .01$) and 7 of the 8 infants in group 2 (Wilcoxon $Z = 2.24$, $p = .025$) listened longer to legal syllables.

The 10.5-month-old infants' listening times were also, on average, longer for the legal than the illegal trials (Legal $M = 8.08$ s, $SE = .89$; Illegal $M = 7.40$ s, $SE = 1.11$). However, this

the second-order constraints in Experiment 2, because the consonants within one of the two sets might be perceived as more cohesive: three of the four consonants in set 1, /b, m, f/, were labials.

difference was not statistically reliable ($t(15) = .91$, $p = .375$, $d = .23$); 8 of the 16 infants listened longer during legal than illegal trials.

Further Results

The listening time difference between legal and illegal syllables was not statistically reliable, but since the mean difference was in the same direction as the 16.5-month-olds, we probed younger infants' ability to learn segment-based second-order constraints in our task by testing an additional 32 10.5-month-olds ($M = 10.3$; Range: 9.6−10.9; 16 females). An additional 6 infants were tested but not included because they were very active (4) or cried (2). Ten trials (4% of the data) were eliminated because the infant never made a criterion headturn (9) or was out of camera view (1). Primary and reliability coders' times were within 750 milliseconds of each other on 82% of trials. The results revealed the same pattern: Infants listened longer during legal trials ($M = 8.06$ s, $SE = .70$) than during illegal trials ($M = 6.65$ s, $SE = .58$). This difference, although in the same direction we found in the main experiment, was again not reliable ($t(31) = 1.87$, $p = .07$, $d = .34$; Wilcoxon $Z = 1.81$, $p = .07$; 22 of 32 infants listened longer to legal trials). The combined data from the 10.5-month-olds in the main experiment and this replication (total $N = 48$) yielded a reliable preference for the legal trials (Legal $M = 8.07$, $SE = .54$; Illegal $M = 6.90$, $SE = .53$; $t(47) = 2.09$, $p = .042$, $d = .30$; Wilcoxon $Z = 2.03$, $p = .042$; 30 of 48 infants listened longer to legal trials).

When presented with second-order constraints, 16.5-month-olds showed a preference for legal syllables; the 10.5-month-olds also showed a preference for legal syllables when we increased the power by testing additional infants. The direction of the effect in Experiment 2, a preference for the legal items, was the opposite of what was found for infants at the same ages who were exposed to first-order phonotactic constraints in the same task (Chambers et al., 2003 for 16.5-month-olds and the current Experiment 1 for 10.5-month-olds). In those experiments, infants showed a robust novelty preference, listening longer to illegal syllables. This systematic relationship between the type of phonotactic constraint presented and infants' preference can clearly be seen in Figure 1. The figure shows the legality preference for each infant (average listening time for legal trials minus average listening time for illegal trials), for Experiments 1 and 2 of Chambers et al., and for the current Experiments 1 and 2.

Why might infants prefer illegal syllables after learning first-order constraints and legal syllables after learning second-order constraints? Preferences for novelty versus familiarity following a familiarization phase depend on multiple factors, including stimulus complexity, the amount of familiarization, and the length of delay between familiarization and test (Hunter & Ames, 1988; Hunter, Ames, & Koopman, 1983; Thiessen, Hill, & Saffran, 2005). Longer familiarization and simpler stimulus patterns both promote novelty preferences, as infants move closer to the point of habituating to the familiarization stimuli. In the present case, however, the duration of familiarization was identical in the experiments examining first- and second-order learning. The 16.5-month-olds in Chambers et al.'s (2003) Experiment 2 received 5 repetitions of a 25-syllable familiarization list, as did the 16.5-month-olds in the present Experiment 2.[4] Nevertheless, a

[4]There was one procedural difference between Experiment 2 in Chambers et al. (2003) and the present Experiment 2. In the previous experiment, the delay between familiarization and test lasted 2 minutes, while in the present Experiment

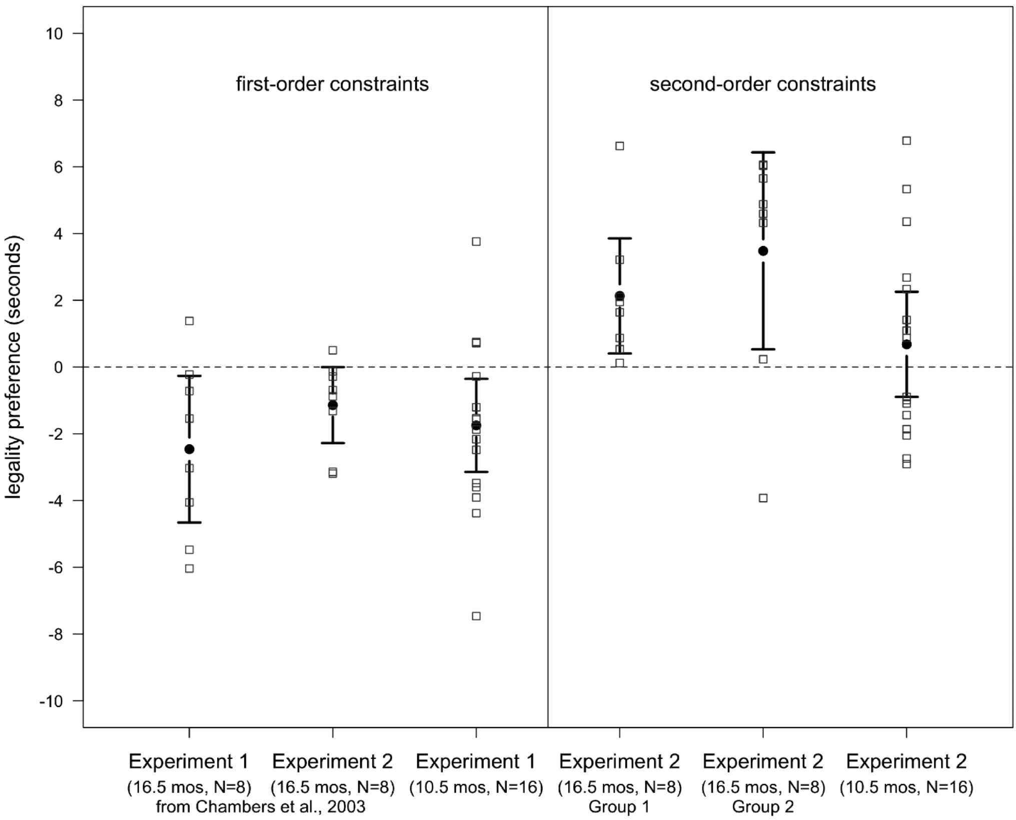

FIGURE 1 Legality preference, the mean difference (in seconds) in listening times for legal minus illegal trials, for each participant (open squares) in Experiments 1 and 2. The filled circles show the mean listening-time difference for each group, and the error bars show 95% confidence intervals. For comparison, we also plotted the data from Experiments 1 and 2 of Chambers et al. (2003), which examined first-order phonotactic learning in 16.5-month-old infants.

comparison of the second-order learning results for each group of 16.5-month-old infants to the first-order learning data of Chambers et al.'s Experiment 2 revealed a significant interaction of constraint type (first- versus second-order) and legality (group 1: $F(1,14) = 14.02$, $p = .002$; group 2: $F(1,14) = 11.92$, $p = .004$), and no other significant effects. Likewise, the procedure for 10.5-month-olds learning both first- and second-order regularities was identical, yet there was a reliable interaction of constraint type and legality, $F(1,30) = 6.03$, $p = .02$, reflecting 10.5-month-olds' smaller and less consistent preference for legal trials

2 it lasted 1 minute. However, this procedural difference is in the wrong direction to independently promote the observed preference difference between Chambers et al.'s Experiment 2 and the present experiment: A longer delay should promote forgetting, and therefore increase the probability of a familiarity preference at test (e.g., Hunter et al., 1983).

following second-order constraints than their preference for illegal trials after learning first-order constraints in Experiment 1. This reliable difference in preference direction for first- and second-order constraints, while holding constant task, materials, and infant age, suggests that the infants found second-order constraints more difficult to learn.

What makes second-order constraints difficult? In principle, both first- and second-order phonotactic constraints could be learned in the same way, by recruiting representations of sequences larger than a single phoneme (e.g., biphones). Prior evidence suggests that child and adult listeners are sensitive to the frequency of particular CV and VC combinations in their native language (Lee & Goldrick, 2008; Peereman, Dubois-Dunilac, Perruchet, & Content, 2004; Sumner & Samuel, 2007; Treiman, Kessler, Knewasser, Tincoff, & Bowman, 2000). However, if sensitivity to the frequency of such sequences of consonants and vowels were the only factor influencing infants' performance in our task, we would expect the learning of first- and second-order constraints to be of equivalent difficulty. To illustrate, Table 1 shows a subset of the syllables in one combination of familiarization and test lists for Experiment 1 (first-order constraints) and Experiment 2 (second-order constraints). The underlined sequences in Table 1 exemplify the behavior of every combination of adjacent consonants and vowels in the experimental materials. Every CV and VC combination found in the legal test syllables had appeared in the familiarization list, whereas none of the CV or VC sequences in the illegal test syllables had appeared in familiarization. This was true for both the first- and second-order constraints. Thus, in terms of shared biphones, the first- and second-order constraints were the same.

However, first- and second-order constraints can be differentiated by attending to individuated segments. In Table 1, the bolded consonant /b/ exemplifies the behavior of every consonant in the experimental materials. For first-order constraints, every legal test syllable had an onset and a coda consonant that had appeared in the same syllable position in several familiarization syllables, whereas every illegal test syllable had an onset and a coda consonant that had *never* appeared in that position in the familiarization list. In contrast, for second-order constraints, every legal *and every illegal* test syllable had an onset and a coda consonant that had appeared in the same syllable position during familiarization. The apparent difference in the ease with which both 16.5- and 10.5-month-old infants learned first- and second-order constraints suggests that

TABLE 1
Examples of Syllables Presented in One Combination of Familiarization and Test Lists Presented to 10.5-Month-Olds in Experiments 1 and 2

Familiarization Syllables		*Legal Test Syllables*		*Illegal Test Syllables*	
Experiment 1: First-Order Constraints					
bap	**b**ig	**b**ag	**b**ip	pa**b**	gi**b**
fas	fip	fap	fis	saf	pif
kag	kis	kas	kig	gak	sik
Experiment 2: Second-Order Constraints					
bap	si**b**	**b**as	pi**b**	pa**b**	**b**is
fas	gif	fap	sif	saf	fig
kag	sik	kas	gik	gak	kis

representations of consonants disentangled from the adjacent vowels played a role in infants' phonotactic learning.

In Experiments 3 and 4, we provide a direct test of this possibility by investigating whether infants readily generalize newly learned first-order constraints to syllables with new vowels. In both experiments, we familiarized 16.5- and 10.5-month-old infants with syllables exhibiting first-order constraints as in Experiment 1; the familiarization syllables included two vowels (e.g., *bap, bis*). The infants then received legal and illegal test trials that contained a transfer vowel, which had never appeared in the familiarization syllables (e.g., *bes*, *seb*). Because half of the test trials consisted of legal syllables and half consisted of illegal syllables, the infants received no evidence that the novel phonotactic constraints applied to syllables containing the transfer vowel. If phonotactic learning in infancy recruits representations of individuated consonants, then infants should generalize the experimental constraints to syllables containing the transfer vowel; they should therefore discriminate legal from illegal syllables during test. In contrast, if representations of individuated consonants play little role, then infants should not readily generalize the experimental constraints to the context of a new vowel, and thus should fail to discriminate legal from illegal syllables.

Experiments 3 and 4 differed in the similarity of the familiarization and transfer vowels, allowing us to probe how freely first-order constraints were generalized, if at all, to syllables containing new vowels. If rapid phonotactic learning is dominated by context-sensitive representations such as CV or VC biphones, we might expect the similarity of the familiarization and transfer vowels to affect the degree of generalization to transfer-vowel syllables.

EXPERIMENT 3

In Experiment 3, the familiarization vowels were /I/ (as in *bit*) and /æ/ (as in *bat*) and the transfer vowel was /ɛ/ (as in *bet*). We chose these materials to increase the probability of generalization to the new vowel, by employing featurally similar vowels in the familiarization and test syllables. The vowels /I/, /æ/, and /ɛ/, although distinct enough to differentiate English words, share many features. All three are lax (as opposed to tense), front (as opposed to back), and unrounded (as opposed to rounded) vowels, differing only in the feature height: /I/ is a high vowel, /ɛ/ is a mid vowel, and /æ/ is low. All of these features play a role in the learning and generalization of phonotactic patterns in English or in other languages (e.g., Finley & Badecker, 2009; Suomi, McQueen, & Cutler, 1997). Consistent with their high featural similarity, the vowels /I/, /æ/, and /ɛ/ are also more often perceptually confused than are vowels that share fewer features (e.g., Hillenbrand, Getty, Clark, & Wheeler, 1995; Peterson & Barney, 1952).

Method

Participants

Participants were 32 healthy term infants, sixteen 16.5-month-olds (M = 16.2; Range: 15.7–16.9; 7 female) and sixteen 10.5-month-old infants (M = 10.5; Range: 10.1–11.3; 8 female). Four additional 16.5-month-olds and eight 10.5-month-olds were tested but not included because they cried (three 16.5-month-olds, four 10.5-month-olds), were very active (one 16.5-month-old, three 10.5-month-olds), or were distracted (one 10.5-month-old).

Materials

Infants received familiarization lists characterized by first-order constraints on the positions of individual consonants (see Table 2), with constraints counterbalanced across participants. The materials used in the familiarization phase were the same syllables used in Experiment 1. Thus, all familiarization syllables contained the vowels /I/ or /æ/, and infants heard syllables in which the consonants /b, k, n, f/ were always onsets and /p, g, m, s/ always codas, or the reverse pattern.

New test syllables containing the transfer vowel /ε/ were recorded in the same manner as the previous materials, by the same speaker. We created two lists of 16 syllables each, one with set 1 consonants as onsets and set 2 consonants as codas (e.g., /bεp/), and one with the opposite assignment of consonants to syllable positions (e.g., /pεb/). These two syllable lists served as the test syllables for all participants. Test trials and test orders were generated following the same constraints described for Experiment 1. Across participants, each transfer vowel syllable occurred equally often as a legal and as an illegal test item.

Apparatus and Procedure

For the 16.5-month-old infants, the apparatus and procedure were as described for Experiment 1. The 10.5-month-old infants were tested in a different laboratory,[5] which involved the following procedural changes: (1) They were tested in a sound-attenuated booth, and no second experimenter accompanied the parent and infant into the booth; (2) no flashing lights

TABLE 2
Examples of Syllables Presented in One Combination of Familiarization and Test Lists in Experiments 3 and 4

Familiarization Syllables		*Legal Test Syllables*		*Illegal Test Syllables*	
Experiment 3: Similar Transfer Vowel					
bag	bip	beg	bep	geb	peb
fap	fis	fep	fes	pef	sef
kam	kig	kem	keg	mek	gek
Experiment 4: Dissimilar Transfer Vowel					
beg	bip	bug	bup	gub	pub
fep	fis	fup	fus	puf	suf
kem	kig	kum	kug	muk	guk

[5]The 10.5-month-olds in Experiments 3 and 4 were tested at the University of Rochester, with the generous support of Richard Aslin.

were used during the familiarization phase; (3) no distracter phase intervened between the familiarization and test phases; and (4) video records were not available, so we assessed coding reliability only for the 16.5-month-olds. Finally, (5) since no video records were available for the 10.5-month-olds, we adopted slightly different criteria for eliminating trials in which the infant did not make a criterion headturn. In Experiments 1 and 2, we used the videotapes of the sessions to verify such trials after the fact. In Experiment 3, all trials with listening times shorter than 1.5 s were assumed to be cases in which the child did not make a criterion headturn, causing the coder to initiate and then immediately end the trial. For consistency, we adopted this revised criterion for both the 16.5- and the 10.5-month-olds.

Primary and reliability coders' times for the 16.5-month-olds were within 750 milliseconds of each other on 78% of trials. Sixteen trials (6%) were missing because the infant did not make a criterion headturn (5 trials for 16.5-month-olds, 10 trials for 10.5-month-olds) or was very active (1 trial for a 10.5-month-old). Each infant contributed at least two legal and two illegal trials to the analyses.

RESULTS AND DISCUSSION

As shown in Figure 2, the infants again discriminated legal from illegal syllables, listening longer to legal than to illegal items. This pattern was tested in a 2 (age) by 2 (legality) mixed-model ANOVA, which revealed a significant main effect of legality ($F(1,30) = 13.06$, $p = .001$), and no effect of age ($F(1,30) = 1.69$, $p = .20$) or interaction of age with legality ($F < 1$). Listening times were reliably longer for legal than for illegal trials, both for the 16.5-month-olds (Legal $M = 8.80$, $SE = .83$; Illegal $M = 6.46$, $SE = .68$; $t(15) = 3.13$, $p = .007$, $d = .81$) and the 10.5-month-olds (Legal $M = 7.60$, $SE = .82$; Illegal $M = 5.58$, $SE = .45$; $t(15) = 2.13$, $p = .05$, $d = .55$). Nonparametric analyses confirmed these differences. Thirteen of the 16 infants at 16.5 months listened longer to legal trials (Wilcoxon $Z = 2.53$, $p = .01$) as did 12 of the 16 infants at 10.5 months (Wilcoxon $Z = 2.02$, $p = .04$).

Thus, infants at both ages learned the phonotactic constraints established by the familiarization syllables and generalized them to syllables containing a vowel that never appeared in familiarization syllables. This result suggests that representations of individuated consonants, disentangled from the vowel context, contribute to phonotactic learning in infancy. In effect, infants learned that, for example, /b/ was an onset and /p/ was a coda, regardless of the vowel.

The direction of the effect in Experiment 3, a preference for the legal items, was the opposite of what we found for infants at the same ages who experienced first-order constraints but were not confronted with a new vowel at test. In tasks that did not introduce a transfer vowel, both 16.5-month-olds (Chambers et al., 2003) and 10.5-month-olds (Experiment 1) showed a novelty preference, listening longer to illegal trials. In preference tasks, reduced similarity between study and test items increases the likelihood of a familiarity preference (Hunter & Ames, 1988). The switch to a familiarity preference when the vowel changed from familiarization to test can therefore be interpreted as evidence that the infants detected the vowel change. The infants in previous experiments who learned first-order constraints and then encountered the same consonants and vowels at test treated the legal trials as too familiar to hold their attention, while those in Experiment 3, who encountered a new vowel at test, did not.

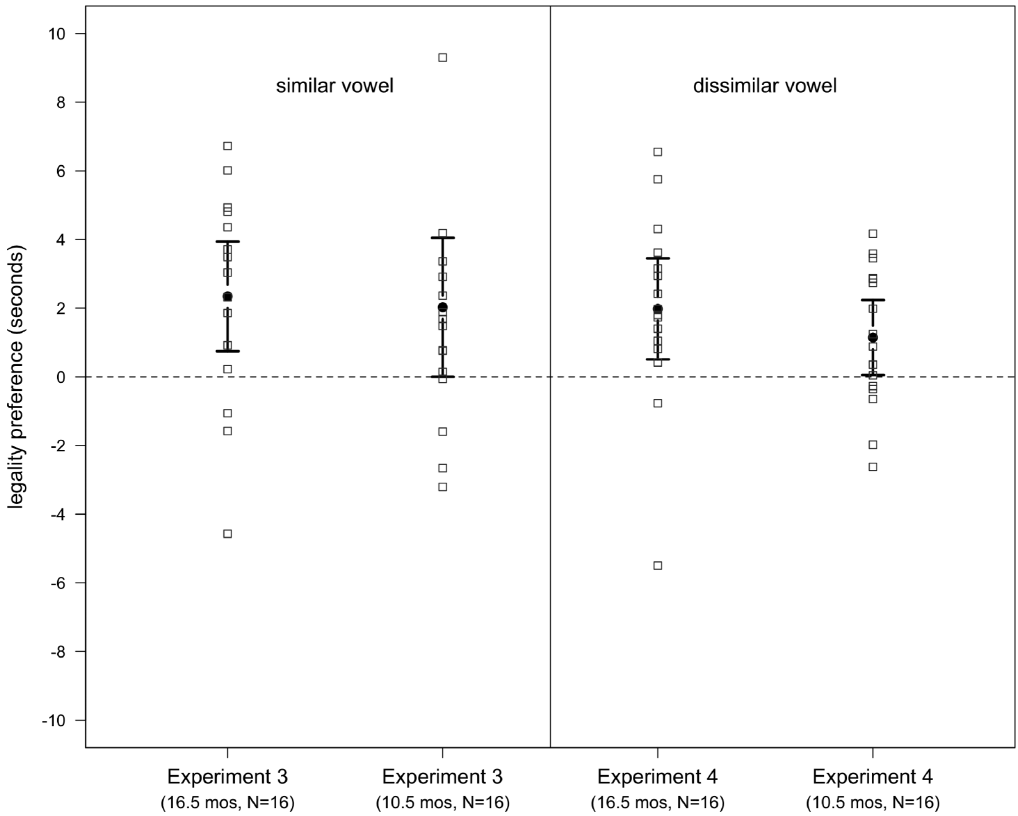

FIGURE 2 Legality preference, the mean difference (in seconds) in listening times for legal minus illegal trials, for each participant (open squares) in Experiments 3 (similar vowels) and 4 (dissimilar vowels). The filled circles show the mean listening time difference for each age group, and the error bars show 95% confidence intervals.

EXPERIMENT 4

In Experiment 4, we asked whether infants would generalize newly learned first-order constraints to a dissimilar vowel. The familiarization syllables contained the vowels /I/ and /ε/ (as in *bit* and *bet*); the transfer vowel used in the test syllables was /u/ (as in *boot*; see Table 2). This transfer vowel shares almost no distinctive features with the familiarization vowels: /I/ and /ε/ are both lax, front, unrounded vowels, and /u/ is a tense, back, rounded vowel. /I/ and /ε/ are also phonetically short vowels, while /u/ is long. As a result of this featural dissimilarity, syllables containing /u/ are essentially never confused with syllables containing /I/ or /ε/ (e.g., Peterson & Barney, 1952). This selection of materials provides a much stronger test of generalization, requiring extrapolation beyond the region of vowel similarity space circumscribed by the training vowels. Such extrapolation can be interpreted as diagnostic of abstract representations in learning (e.g., Marcus, 2001). Evidence of generalization to this dissimilar transfer vowel would strongly support the hypothesis that infants can represent first-order constraints as simple links between an individuated consonant and a syllable position, independent of the contexts in which those constraints were established.

Method

Participants

Participants were 32 healthy term infants, sixteen 16.5-month-olds ($M = 16.2$; Range: 15.5–16.8; 8 female) and sixteen 10.5-month-olds ($M = 10.7$; Range: 10.0–11.2; 5 female). Thirteen additional 16.5-month-olds and five 10.5-month-olds were tested but excluded because they cried (six 16.5-month-olds, two 10.5-month-olds), were very active (five 16.5-month-olds, two 10.5-month-olds), were distracted (one 10.5-month-old), or listened for the maximum amount of time on four or more of the eight test trials (two 16.5-month-olds).

Materials

The materials were created as described for Experiment 3 except that the familiarization vowels were /I/ and /ε/ and the transfer vowel used in the test syllables was /u/ (see Table 2).

Apparatus and Procedure

The apparatus and procedure were as described for Experiment 3, including the modifications specified for the 10.5-month-olds.

Primary and reliability coders' times for the 16.5-month-olds differed by less than 750 milliseconds on 89% of trials. Seventeen trials (7%) were treated as missing because the infant never made a criterion headturn (8 trials for 16.5-month-olds, 7 trials for 10.5-month-olds), was very active (1 trial for a 10.5-month-old), or was out of camera view (1 trial for a 16.5-month-old). Each infant contributed at least two legal and two illegal trials to the analyses.

RESULTS AND DISCUSSION

As shown in Figure 2, infants again discriminated legal from illegal syllables, listening longer to legal than to illegal items. A 2 (age) by 2 (legality) mixed-model ANOVA revealed a significant main effect of legality ($F(1,30) = 13.21$, $p = .001$), and no effect of age or interaction of age and legality (Fs < 1). Listening times were reliably longer for legal than for illegal trials, both for the 16.5-month-olds (Legal $M = 8.81$, $SE = 1.08$; Illegal $M = 6.84$, $SE = .81$; $t(15) = 2.87$, $p = .01$, $d = .74$) and for the 10.5-month-olds (Legal $M = 8.08$, $SE = .80$; Illegal $M = 6.93$, $SE = .71$; $t(15) = 2.24$, $p = .04$, $d = .58$). Nonparametric analyses confirmed these differences: 14 of the 16 infants at 16.5 months listened longer to legal trials (Wilcoxon $Z = 2.69$, $p = .01$), as did 11 of the 16 infants at 10.5 months (Wilcoxon $Z = 2.02$, $p = .04$). The preference for legal items replicated the preference direction found in Experiment 3.

Thus, as in Experiment 3, infants at both ages learned the new first-order phonotactic constraints during the familiarization phase, and spontaneously generalized them to syllables containing a different vowel during the test phase. They did so even though in Experiment 4 the transfer vowel was much less similar to the familiarization vowels than it was in Experiment 3, suggesting that representations of individuated consonants, abstracted away from the adjacent vowel context, contribute to phonotactic learning in infancy. A comparison of the results of Experiments 3 and 4 suggests that the degree of similarity between the familiarization and transfer vowels had little effect on infants' responses. A 2 (Experiment) by 2 (age) by 2 (legality) mixed-model ANOVA yielded a main effect of legality ($F(1,60) = 25.52$, $p < .001$), but no main effects or interactions involving age or Experiment (Fs < 1).

GENERAL DISCUSSION

Recent experiments have shown that infants, like adults, adapt to new phonotactic patterns from brief listening experience (e.g., Chambers et al., 2003; Cristià & Seidl, 2008; Saffran & Thiessen, 2003; Seidl & Buckley, 2005; Seidl et al., 2009). The goal of the present work was to investigate how infants represent the phonological sequences they encounter and how they generalize across them to detect phonotactic patterns. We found evidence for two main conclusions. First, young infants can learn new first- and second-order constraints on the positions of individual consonants (in addition to feature classes). Second, infants learn first- and second-order constraints differently, recruiting context-free representations for first-order constraints. These findings shed new light on the role of the segment in phonotactic learning in infancy.

Building on evidence that infants readily learn new first- and second-order constraints defined in terms of feature-based classes, we asked whether young infants could also learn first- and second-order phonotactic constraints on the positions of individual consonants. We found that 16.5- and 10.5-month-olds could do so. Infants were familiarized with syllables displaying first-order constraints (Experiments 1, 3, and 4) or second-order constraints in which consonant position depended on the vowel (Experiment 2). Crucially, the sets of consonants constrained to a particular position could not be described in terms of a small set of phonetic features. In each case, the infants discriminated new legal from illegal syllables in the test phase (although we found weaker evidence that 10.5-month-olds learned second-order segment-based constraints in our brief task; we return to this issue below). Thus, infants as young as 10.5 months of age detected new phonotactic patterns at the level of the segment, and generalized them to the novel syllables presented in the test phase. These results add to evidence of the impressive precision of infants' speech processing in phonological learning tasks. To detect segment-level phonotactic patterns, infants must identify and keep track of the sequencing of individual segments, and do so precisely enough to learn different distributional patterns for featurally similar (thus potentially confusable) segments.

The present experiments yielded two kinds of evidence that infants do not learn first- and second-order constraints in the same way. Thus, representations of individuated consonants and vowels, disentangled from their adjacent contexts, contribute substantially to infant phonotactic learning.

First, infants learned first-order constraints more readily than second-order constraints. Evidence that 16.5-month-olds had greater difficulty learning second-order constraints emerged in the consistent preference reversal following familiarization with second- as opposed to first-order constraints, even though testing included only segments that had appeared during familiarization. This preference reversal, in experiments holding stimulus and task features constant, can be understood as an indication that the infants found the second-order constraints more difficult to learn. Our interpretation of this preference reversal was supported by the clear difference in the magnitude and consistency of the learning effect for 10.5-month-olds. These younger infants showed a robust preference for the illegal items when learning first-order constraints, but when exposed to second-order constraints they showed a noticeably weaker preference for the legal items. Taken together, these data suggest that infants found it natural to learn and generalize phonotactic patterns at the level of the segment, independent of context and, therefore, had more difficulty learning new patterns that depended on that context.

Second, 16.5- and 10.5-month-old infants spontaneously generalized newly learned first-order phonotactic constraints to syllables containing a new vowel. They did so whether the transfer vowel was similar to the familiarization vowels (Experiment 3) or dissimilar from them (Experiment 4). Evidence that infants spontaneously generalized first-order constraints to syllables containing new vowels again suggests that they found it natural to represent and generalize phonotactic patterns at the level of the segment, independent of its local context.

Our infant results mirror recent findings in experiments with adults (Chambers et al., 2010). In a speeded repetition task, adults heard and repeated CVC syllables exhibiting first-order constraints on consonant position. The adults learned the constraints, as shown by shorter latencies to identify and repeat test syllables that were legal rather than illegal with respect to the experimental constraints. This legality advantage appeared whether the test syllables contained one of two familiarization vowels, or a new, transfer vowel, and whether the transfer vowel was similar to the familiarization vowels, or quite different from them.

Both for adults and infants, spontaneous generalization of newly learned phonotactic constraints to new vowels implies that individual consonants must be easily separable from adjacent vowels in the representations underlying phonotactic learning. This conclusion is consistent with other recent evidence for the separability of consonants and vowels in implicit learning about speech. For example, adults identified words based on high transitional probabilities between non-adjacent consonants (e.g., pVgVtV) even though intervening vowels varied freely (Newport & Aslin, 2004; see also Bonatti, Peña, Nespor, & Mehler, 2005). Additional evidence for a representational divide between consonants and vowels comes from studies of adaptation in speech production. When adults heard formant-shifted versions of their own speech, such that an intended /ɛ/ (as in *bet*) would be heard as an /i/ (as in *beat*), they adjusted their productions to compensate for the distortion (Houde & Jordan, 1998). This compensation generalized to novel consonant contexts. These data, like the present findings, implicate a representational distinction between consonants and vowels that influences what adults and infants learn from experience with phonological sequences.

Taken together with prior results, the present findings provide new evidence of infants' flexibility in encoding and analyzing phonotactic patterns. Prior evidence tells us that 9-month-olds find it easier to learn phonotactic patterns defined over feature-based classes than over individual segments (Saffran & Thiessen, 2003). Nonetheless, by 10.5 months, infants represent speech sound distributions flexibly enough to learn about the behavior of individual segments. Similarly, we found evidence that infants found it easier to detect first- than second-order phonotactic patterns. Nonetheless, by 10.5 months, infants show signs that they can represent speech sound distributions flexibly enough to learn second-order constraints, and by 16.5 months, they demonstrate robust second-order constraint learning. Similar evidence of flexibility has been found in adult phonotactic learning. Adults learn novel first- and second-order constraints (Dell et al., 2000; Onishi et al., 2002; Warker & Dell, 2006) and novel feature-based and segment-based constraints (Dell et al., 2000; Finley & Badecker, 2009; Goldrick, 2004; Onishi et al., 2002; Warker & Dell, 2006).

Thus infants, like adults, have the flexibility to learn a wide range of phonotactic constraints. The nature of those constraints depends on the evidence that they encounter in their experience with phonological sequences. This evidence that rapid phonotactic learning during infancy is flexible enough to support the detection of phonotactic patterns at multiple levels of phonological analysis, in turn, lends additional support to the claim that phonotactic knowledge arises from ongoing language experience.

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