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On the Learning of Arbitrary Phonological Rules

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It has been suggested that language learners prefer phonologically natural patterns over unnatural ones (McCarthy & Prince, 1995; Tesar & Smolensky, 1993, 2000). Various researchers have cited evidence for this assertion based on production (Demuth, 1995; Gnanadesikan, 1995) and perception (Jusczyk, Smolensky, & Allocco, 2002). Two experiments presented in this article test whether 9-month-old infants learn unmarked, phonetically grounded patterns more easily than marked, arbitrary ones. Experiment 1 tested phonetically grounded and arbitrary patterns involving manner of articulation; results revealed that infants showed no specific preference for the grounded patterns. Experiment 2 tested a pattern in place of articulation; once again, infants showed no specific preference for the grounded distributions. We take this as evidence that infants can, in fact, learn arbitrary phonological patterns and as evidence against a bias for grounded patterns in the grammar of infants at this age.

Certain sound patterns are frequently found in the world's languages; many others may be rare or unattested. For example, the assimilation of a nasal consonant to the place of articulation of a following stop, such as /anpa/ becoming [ampa], is extremely common across languages and is seen in English *in-ept* versus *im-possible*. Assimilation in the opposite direction, such as /anpa/ becoming [anta], is quite unusual, if it occurs at all. Although a variety of factors might play a role in such asymmetries, including overall complexity of cognitive representations, the crucial explanation in nasal assimilation and many other phonological patterns is that the direction of change is phonetically grounded (cf. Archangeli & Pulleyblank, 1994;

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Hayes, 1999): That is, the pattern arises due to articulatory or auditory phonetic factors. In the case of nasal place assimilation, the main percept of the nasal consonant [n] is nasalization of the preceding vowel, whereas the place of articulation of the following stop consonant [p] is robustly perceptible because it is followed by a vowel (Ohala & Ohala, 1993). These conditions make it quite common for the nasal's place of articulation to be perceived as the same as the following stop consonant and highly unlikely that /anpa/ would be reinterpreted by listeners as /anta/. This latter type of change is phonetically arbitrary because it would not arise directly as the result of phonetic pressures.

The phonetically grounded sound patterns typical of the world's languages, such as nasal place assimilation, are also termed *natural* (because they are the natural result of phonetic factors) or *unmarked* (because they are more frequent than *marked* forms in languages of the world). In most of this article, we prefer the term *phonetically grounded* to both of these alternatives. *Naturalness* is relatively vague, and the particular sense that we have in mind, phonetically natural, is exactly groundedness. *Markedness* is also quite a general term; it evokes notions of simplicity and relative frequency, which these experiments do not address.[1]

Phonological research typically attempts to capture the distinction between marked and unmarked patterns; as McCarthy (1988) put it, "The goal of phonology is the construction of a theory in which cross-linguistically common and well-established processes emerge from very simple combinations of the descriptive parameters of the model" (p. 84). If the theory is constructed properly, it should be simple to represent natural or unmarked patterns and relatively more difficult to represent unnatural or marked patterns; at least some unattested patterns will be impossible to represent. Although general cognitive or computational factors may also be relevant, the unmarked patterns that predominate in the phonological literature are phonetically grounded ones; in fact, McCarthy makes his statement in the context of developing a feature geometry that models (at a more abstract level) the organization of phonetic articulation.

A related claim is that in the initial state of the grammar, infants prefer phonetically grounded and unmarked phonological alternations over arbitrary and marked ones (McCarthy & Prince, 1995; Tesar & Smolensky, 1993, 1998, 2000); evidence has been adduced from the study of production (Demuth, 1995; Gnanadesikan, 1995; Pater & Paradis, 1996) and perception (Jusczyk, Smolensky, & Allocco, 2002;

[1] A further advantage of focusing on phonetically grounded processes, rather than markedness in some more general sense, is that some recent approaches to phonology prefer to express generalizations directly in terms of their phonetic motivations (cf. Hayes, Kirchner, & Steriade, 2004) and our studies are relevant to those theories as well. Although our stimuli are designed with respect to the phonological categories of segments, rather than gradient phonetic differences, they nevertheless contrast possible synchronic patterns that we would expect to arise from phonetic pressures as modeled in such approaches.

Saffran & Thiessen, 2003). Results from recent adult perception experiments have also suggested that phonetic groundedness may have an effect on phonemic categorization (Gilkerson, 2003; Newport & Aslin, 2004). For example, Gilkerson found no groundedness preference for voice onset time but did find one for the learning of a uvular–pharyngeal contrast. Specifically, she found easier learning of a normal uvular–pharyngeal distinction than an artificial boundary along that dimension (one in the middle of the pharyngeal domain). This finding may support innate features of some kind, but it is also possible that there is some kind of quantal effect (Stevens, 1989) that might be learned rather than innate; that is, if the phonetically natural boundary between these places of articulation is based on the most distinct auditory transition, then this (rather than an innate cognitive bias) might affect categorization. For example, distinctions in the first formant above 550 may be less perceptible in the presence of the other acoustic properties of pharyngeals, and this fact may explain the ease in learning the more grounded distinction. In addition, Newport and Aslin (2004) found that English speaking adults were not able to acquire regularities dependent on nonadjacent syllables (rare in the world's languages) but were able to learn regularities between nonadjacent consonants and vowels located in adjacent syllables (common in the world's languages).

Our goal is to investigate whether the groundedness of a phonotactic pattern affects its learnability for infants. In the two experiments presented here, we exploit infants' sensitivity to the frequency distribution of speech sounds in the input (Chambers, Onishi, & Fisher, 2003; Maye, Werker, & Gerken, 2002; Saffran & Thiessen, 2003) to test whether infants learn phonetically grounded patterns differently from arbitrary ones. Our results call into question results of previous perception studies claiming that infants begin with a preference for phonetically grounded patterns.

PREVIOUS RESEARCH

Two recent studies (Jusczyk et al., 2002; Jusczyk, Smolensky, Arnold, & Moreton, 2003) investigated the preferences for unmarked over marked alternations in 4.5-, 10-, 15- and 20-month-old infants. These studies focused on nasal-place assimilation and approached their analysis from the perspective of Optimality Theory (OT; Prince & Smolensky, in press). This influential approach posits that a grammar consists of ranked, violable constraints. These constraints are innate and therefore universal; languages differ in the ranking of the constraints, and the child learning a language is faced with the task of reranking constraints to model the ambient language. Constraints are divided into two types: markedness and faithfulness. Markedness constraints prefer output forms with unmarked structures; specifically, the constraint AGREE(Place)—segments share a place of articulation—would penalize [anpa] relative to [ampa] because it lacks nasal-place agreement. Faithfulness constraints, on the other hand, prefer that output forms remain "faithful" to input forms; for example, IDENT(Place)—output segments have the same place of articulation as they do in the input—would penalize [ampa] if it is derived from the underlying string /anpa/ because the nasal's place of articulation has changed.

It is well known that early child speech production favors unmarked structures,[2] such as simple consonant (C) vowel (V) syllables that differ from the adult model by dropping final consonants (Fikkert, 1994; Lewis, 1951) and simplifying consonant clusters (Fikkert, 1994; Leopold, 1947). In OT, this observation can be modeled by an initial ranking of the grammar of markedness constraints dominating faithfulness constraints (Smolensky, 1996; Tesar & Smolensky, 2000). Thus, an infant is assumed to possess a grammar that includes the ranking AGREE(Place) >> IDENT(Place) and for that reason will produce the output [ampa] even if the adult form, which serves as the input, is unassimilated /anpa/. Only with the learning of surface forms that violate specific markedness constraints does the child adjust the ranking to achieve a more adult-like, and more marked, grammar. Like many OT markedness constraints, AGREE(Place) is phonetically grounded, as discussed. As a result, the claims made about markedness in this context are also claims about the status of phonetically grounded processes.

Infants in the two studies by Jusczyk and colleagues (Jusczyk et al., 2002; Jusczyk et al., 2003) listened to several different lists made up of sets of three words, or "triads," that respected either faithfulness or markedness constraints relevant to nasal place assimilation. Each triad consisted of two monosyllabic pseudowords followed immediately by a bisyllabic item made by combining the previous two, with or without a change in nasal place. For example, the triad *am*, *da*, *anda* respects the markedness constraint AGREE(Place), but *am*, *da*, *amda* does not because it includes the sequence [md]. This much can be said based solely on the surface forms; but a further assumption of the methodology is that the infant will interpret the third element, *anda*, as derived by concatenation of the first two. That is, the authors asserted that [anda] in the triad *am*, *da*, *anda* is a violation of the faithfulness constraint IDENT(Place) because [anda] is taken to be derived from [am] plus [da]. In contrast, the triad *an*, *da*, *anda* would violate neither sort of constraint. We return to this issue shortly.

Using the Headturn Preference procedure (HPP) to test infants on both the markedness and faithfulness word lists, Jusczyk et al. (2002) found that 4.5-month-olds, 10-month-olds, and 20-month-olds preferred the *anda*-type lists that respected markedness constraints over the *amda*-type lists that respected faithfulness constraints. Fifteen-month-olds, however, showed no such preference. Jusczyk et al. interpreted the lack of preference at 15 months as evidence that infants at this age are in a state of indeterminate ranking, or in the process of reranking their constraints; they also suggest that this indeterminate period may interact with gains in morphological acquisition that occur at around this age.

[2]Of course, children's productions appear to be influenced by the frequency of the form in the target language (Kehoe & Stoel-Gammon, 2001; Stites, Demuth, & Kirk, 2004; Zamuner, 2003).

Subsequent studies of this markedness preference with 4.5-month-olds yielded decidedly less clear results (Jusczyk et al., 2003). In two experiments, for example, infants were offered stimuli in which the stop assimilated to the preceding nasal (*an*, *bi*, *andi*), a very unnatural pattern without phonetic grounding; the participants showed no clear preference between the natural phonological process *an, bi, ambi* and unnatural *an, bi, andi,* or between unassimilated *an, bi, anbi* and unnatural *an, bi, andi*. Based on the difficulty of explaining the disappearance of the preference at 15 months, as well as the lack of results in the follow-up studies, the results presented by Jusczyk et al. must be considered inconclusive with respect to infants' preferences for natural over unnatural alternations.[3]

It should in addition be noted that the A, B, AB triad procedure used in Jusczyk et al. (2002; Jusczyk et al., 2003) is quite novel in infant research, and its validity has not been established by previous studies. In particular, researchers do not know whether infants will treat the final item in the triad as the concatenation of the first two or simply as an independent word. Thus a preference for the triad containing *anda* rather than *amda* might have nothing to do with a hypothetical underlying form /amda/ shared by the two pseudowords; it might relate instead to a preference for [nd] strings over [md]. This assimilation generalization is also true of the ambient language (American English), and any preference for these English-like patterns cannot be attributed to universal grammar without further evidence. In other words, the infants could be biased against [amda] stimuli by the fact that in an English-speaking environment they hear words with nasal-place agreement, such as *impossible* and *simple*, considerably more often than words without assimilation, such as *unpopular.*[4]

THESE STUDIES

Given the inconclusive results in previous studies, the question remains: Do young infants really have innate preferences for unmarked, phonetically grounded patterns, or will they learn marked, phonetically arbitrary patterns as easily? In these studies, we investigated this question using only rules (i.e., pattern generalizations) that do not occur in English, to avoid confounds with the ambient language. We

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[3]Although the direction of assimilation in place from the obstruent to the following nasal or vice-versa makes a difference in the construction of a restrictive phonological theory (cf. Pater, 1999), the outputs *ambi* and *andi* are both natural, unmarked structures.

[4]We searched the Switchboard speech corpus (Godfrey, Holliman, & McDaniel, 1992), consisting of about 1.4 million words of conversational American English, to assess the presence of phonological features in the children's ambient language. Of 146,696 trochaic words (two syllables, initial stress), 10,360 contain a medial nasal-stop cluster with the same place of articulation, and only 1,055 have such a cluster without place agreement. Clearly the ambient language is very strongly biased toward assimilated nasal-stop clusters in this context. Note also that if a word such as *unpopular* is articulated with little or no alveolar nasal (just nasalization of the vowel), it will often be perceived as containing an assimilated nasal consonant (Ohala & Ohala, 1993).

wanted infants who would be able to learn a new pattern, so we tested 8.5- to 9.5-month-olds because it has been shown that infants at this age are still able to learn some new phonological units; for example, they can still perceive some non-native phoneme contrasts (Polka & Werker, 1994; Werker & Tees, 1984; among others). In addition, previous phonotactic learning studies have shown that infants as old as 16 months are capable of learning novel phonotactic patterns (Chambers et al., 2003). Crucially, 8.5 to 9.5 months precedes the point at which Jusczyk et al. (2003) suggested that infants start to rerank their constraints (before 15 to 20 months), so any markedness preference should still be in force. Nonetheless, at this age infants do seem to have some sense of their own language's phonotactics: They prefer phonotactically legal words over nonlegal ones (Friederici & Wessels, 1993), prefer to listen to unfamiliar words of their native language over unfamiliar words in a foreign language (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993), and show a preference for phoneme sequences that do not violate the phonotactics of their native language (Jusczyk, Luce, & Charles-Luce, 1994). It might therefore be expected that learning novel phonotactics, especially unnatural phonotactic patterns, is difficult for these children. Especially within the context of OT, if infants have innate constraints that favor various unmarked patterns, but no constraints favoring marked patterns, there ought to be an asymmetry in learning. One basic question, then, is whether infants would be able to learn the patterns we presented after brief familiarization, regardless of the unmarked status that comes with phonetic groundedness.

To test the hypothesis that grounded rules may be learned better (faster and more easily) than arbitrary ones, we use an established procedure for statistical grammar learning in infants (e.g., Gómez & Gerken, 1999; Marcus, Vijayan, Rao, & Vishton, 1999; Maye et al., 2002; Saffran, Aslin, & Newport, 1996). In these studies, researchers looked at the degree to which infants were able to use transitional probabilities or statistical information to identify grammatical units or groupings. In Gómez and Gerken, for example, infants were tested on their ability to use statistics to glean information about word order. Participants were familiarized with a probabilistic word order and were able to distinguish the more probabilistically familiar word order from a probabilistically novel one, indicating that they were able to use statistical information concerning the order of words.

The methodology exploited here is also the same used in recent studies of phonotactic rule learning in adults (Newport & Aslin, 2004; Onishi, Chambers, & Fisher, 2002) and infants (Chambers et al., 2003). In Chambers, Onishi, and Fisher (2003), 16.5-month-olds were familiarized with CVC syllables in which particular consonants were restricted to either onset or coda position depending on the vowel; for example, in one set, /p/ occurs only in onset position before /ɪ/ (e.g., /pɪm/), and in another set it occurs only in coda position after /æ/ (e.g., /mæp/). The infants were familiarized with sets of words with similar restrictions for approximately 3 min, then tested on novel lists of words that either followed or did not follow the familiarized pattern. Infants listened reliably longer to words that did not follow the familiarized pattern (i.e., followed a new pattern). These kinds of phonotactic restrictions are actually quite arbitrary[5]—the formulations did not follow typical patterns of vowel–consonant interaction—so the fact that these infants were able to learn them was further motivation for our study. In addition, these rules were difficult in that they were disjoint: There was no single generalization that could cover all instances of consonant and vowel restrictions. The child needed to learn that for the consonant /p/ and the vowel /æ/ there was one rule, and for the consonant /p/ and the vowel /ɪ/ there was a completely different rule. Our rules, in contrast, allow the child to make one unified generalization and are therefore potentially easier to learn.

In all of these studies, infants or adults were familiarized for 2 to 3 min with a series of strings that display a distinct pattern. Then the participants were tested on strings or word lists that are either consistent or inconsistent with that pattern. The participants showed a pattern of preference for the inconsistent forms. Our experiments are set up the same way. Likewise, in our experiments, we predict that if learning of the rule occurs, the infants will attend longer to the unfamiliar or novel word lists.

In Experiment 1, we tested a pattern involving manner of articulation. In our phonetically grounded pattern, fricatives and affricates, but not stops, occur intervocalically (similar to intervocalic spirantization in many languages). In our arbitrary pattern, fricatives and affricates, but not stops, occur word-initially (not attested in any language we know of). In our phonetically grounded pattern in Experiment 2, labial consonants are followed by round vowels, coronal consonants by front vowels, a rule very similar to consonant–vowel assimilation rules found, for example, in Cantonese (Flemming, 2003) and Maltese (Hume, 1996; see also Flemming, 2003). In the arbitrary pattern, labial consonants are followed by high vowels, and coronal consonants by midvowels, which is not attested in any language to our knowledge. As mentioned, crucially, none of these rules occur in English, the infants' immediate linguistic environment.

Both Experiments 1 and 2 were statistical learning studies; however, in these studies the infant must also have at her disposal certain linguistic knowledge concerning the place and manner of segments—that is, distinctive phonological features—that could not be gleaned from pure statistics alone. This information must then be used to generalize to new forms. In fact, much recent work suggests that infants have both phonemic and subphonemic awareness from quite early in life (Johnson, 2003) and that this information works most often in combination with statistical and suprasegmental cues (Johnson & Jusczyk, 2001; Thiessen & Saffran, 2003). We predict that the infants will be able to generalize to new forms and have a sensitivity to phonological features.

[5]Goldrick (2004) also successfully taught adult participants arbitrary patterns: For example, a coda voicing rule in which /f/ is confined to onset, while, /v/ appears in both onset and coda.

Whether or not the “rule” learning in our experiments is purely linguistic or is a combination of a general learning strategy and linguistic knowledge is left unanswered by this methodology. Nonetheless, we have constructed the experiment such that it is impossible for infants to rely on a general learning strategy alone. They must possess some kind of knowledge or “scaffolding” of phonological features—such as voice, place, and manner—to form generalizations based on the familiarization forms. Previous work with older children has shown that they are sensitive to featural differences in word recognition tasks. For example, Swingley and Aslin (2002) showed that 14-month-old children recognized words as mispronunciations when they varied from the target in only a place feature. In subsequent studies, Swingley (2003) showed that 19-month-old children were also sensitive to differences in voicing. Even very young infants may be sensitive to small differences in features (Bertoncini, Bijeljac-Babic, Jusczyk, Kennedy, & Mehler, 1988; Eimas, 1999; Werker & Tees, 1984), and there is also some evidence that infants are able to extract these features. For example, Hillenbrand (1983) found that 6-month-olds were able to learn a correspondence between syllables that shared an initial consonant with a similar feature. However, there is little evidence that infants are able to use these features in language learning. In fact, some authors suggest that young children have such underspecified representations that they may not even notice featural distinctions or recognize features until they have acquired a large enough lexicon that such specifications are crucial to differentiating between items (Metsala & Walley, 1998). Another perspective (usually expressed in OT: e.g., Gnanadesikan, 1995; Smolensky, 1996) is that infants begin with structure and simply reorganize that structure in accordance with the input, but that an awareness and ability to use phonological features is an innate capacity. The results of the studies discussed here will also shed some light on this debate. Specifically, if infants are able to generalize a feature or set of features as a rule of their language, then clearly these features are somehow present in the infant’s system at quite a young age.

EXPERIMENT 1

The purpose of Experiment 1 was to determine whether 8.5- to 9.5-month-old infants would learn phonetically grounded manner alternations better than arbitrary manner alternations. Previous work suggests that infants are sensitive to manner from quite a young age. For example, Swingley and Aslin (2002) showed that 14-month-olds distinguish a nonword pronunciation (*vaby)* from a known word pronunciation (*baby)* when they differ only with respect to manner.

Infants were familiarized and tested using the HPP (Jusczyk & Aslin, 1995; Kemler-Nelson et al., 1995) and a familiarization-test paradigm similar to that of Marcus et al. (1999). Group 1 was familiarized with strings (three-word sequences) with pseudowords that followed our phonetically grounded manner pattern in which fricatives and affricates occurred only between two vowels, and no stops occurred in that position ([pasat nodʒɛt mitʃa]). Given that children's early production shows evidence of a preference to begin words with less sonorant segments (Pater, 1997), we might expect this rule to be relatively easy to learn. Group 2 was familiarized with strings with pseudowords that followed our arbitrary manner pattern in which fricatives and affricates, but no stops, occurred only word-initially ([sapat dʒonɛt tʃima]). In the test phase, infants in both Group 1 and Group 2 heard strings with novel pseudowords (also containing novel fricatives) that followed either the phonetically grounded pattern or the arbitrary pattern. A search of the Switchboard speech corpus (Godfrey, Holliman, & McDaniel, 1992) revealed that both of the patterns we taught infants were of comparable frequency in the ambient language. Of the 6,413 trochaic words (lexical frequency) in the corpus, 213 contained an initial stop and an intervocalic continuant, and 212 contained an initial continuant and an intervocalic stop.

If infants follow the pattern predicted by Tesar and Smolensky (1993), then they should learn only the phonetically grounded rule (or learn it with greater ease) and will show a preference for words that do not follow that rule in the test phase of the experiment. If, however, infants in both groups show a preference for words that do not follow the rule that they learned regardless of the phonetic grounding of the rule, this would suggest that they are not biased toward either kind of alternation.

Method

Participants. We tested 29 infants from monolingual English-speaking households in the Baltimore area in the infant lab at Johns Hopkins University.[6] Five infants were excluded from the final analyses for crying or fussing (4) and failing to look at any test stimulus for an average of more than 2 sec (1). Of the remaining 24 participants, 14 were girls, and 10 were boys. These infants were an average age of 9 months and 7 days (range = 8 months, 18 days to 9 months, 23 days) and were primarily from middle class households. Twelve infants were randomly assigned to each of two experimental conditions.

Design. The overall design of the experiment involved familiarizing each infant for 2 min with strings of words that followed a particular phonological pattern and then examining their preferences for novel strings that either did or did not follow this pattern. There were two groups: Group 1 was familiarized with a phonetically grounded pattern, and Group 2 was familiarized with an arbitrary pattern.

[6]Experiment 2 was conducted at Purdue University. The same lights, button box, and computer were used for both Experiment 1 and 2. In addition, the HPP booth at Purdue was built to exactly the same specifications as at Hopkins. A study on clause segmentation at Purdue replicated results on the same study at Hopkins, showing that the HPP at Purdue was comparable to the one at Hopkins. For any further questions on the replicated study, please contact Amanda Seidl.

Stimuli. The familiarization stimuli for each group consisted of 16 different strings made up of three words each and separated by a 1-sec pause between the strings. The familiarization stimuli adhered to several phonological constraints, including a limited set of consonants and vowels:

1. The syllable structure was always either CVCV or CVCVC.
2. The only fricatives and affricates used were [s, z, dʒ, tʃ].
3. The only noncontinuant consonants were [t, d, b, p, m, n].
4. The only vowels were [o, u, a, ɛ, ɪ].
5. The only consonants to occur word-finally were [n, t].
6. The vowel [ɛ] was not used word-finally because it cannot occur there in English words.

The stimuli were produced in a sound-attenuated booth by a female speaker of American English in infant-directed speech. Because infants begin to segment words from the speech stream at 7 months (Jusczyk & Aslin, 1995) and could have potentially recognized words from previous exposure to English, words judged similar to common vocabulary items of English were dropped and replaced by other random words. In addition, all words were pronounced with trochaic stress. The following two passages were recorded.[7]

Familiarization (phonetically grounded):
pasat nodʒɛt mitʃa, tɛdʒo dazɛn buso, ditʃa bɛdʒo modʒu,
pazu mɛsa natʃɛt, dasat todzɛt notʃa, mɛdʒo tazɛn puso,
tatʃa pɛdʒo nodʒu, bazu nɛsa matʃɛt, posot nudʒo matʃo,
todʒɛt dozun bosu, dotʃo bidʒi mudʒo, poza masɛn nɛtʃa,
disit tɛdʒɛn natʃo, midʒo tɛzon piso, titʃɛt podʒɛn nodʒi,
buza nasɛt mitʃɛn

Familiarization (Arbitrary):
sapat dʒonɛt tʃima, dʒɛto zadɛn subo, tʃida dʒɛbo dʒomu,
zapu sɛma tʃanɛt, sadat dʒotɛt tʃona, dʒɛmo zatɛn supo,
tʃata dʒɛpo dʒonu, zabu sɛna tʃamɛt, sopot dʒuno tʃamo,
dʒotɛn zodun sobu, tʃodo dʒibi dʒumo, zopa samɛn tʃɛna,
sidit dʒɛtɛn tʃano, dʒimo zɛton sipo, tʃitɛt dʒopɛn dʒoni,
zuba sanɛt tʃimɛn

As noted previously, in the schema $C_1VC_2V(C)$ the phonetically grounded stimuli have oral stops in C_1 but not in C_2 position and fricatives or affricates in C_2

[7]All stimuli in this article are presented in the International Phonetic Alphabet. Primary stress is uniformly on the first syllable and is not transcribed.

but not in C_1 position. The arbitrary pseudowords were created by swapping the first and second consonants of each of the phonetically grounded pseudowords. This reversed the positional restrictions for stops and fricatives, such that fricatives and affricates occurred only initially, and no stops occurred in that position. All the vowels remained the same between phonetically grounded and arbitrary versions, as did any final consonant.[8]

The test stimuli consisted of 8 different strings, 4 phonetically grounded strings and 4 arbitrary strings. As in familiarization, each string was made of three pseudowords. Words in the test phase began with novel consonants (not used in familiarization) as well as familiar consonants (already used in familiarization) and contained vowels that were not in the familiarization stimuli. These new consonants and vowels were used to examine whether infants were truly generalizing according to the classes as defined by standard features, such as [continuant]. The modifications to the constraints on these words were as follows:

1. The novel fricative consonants were [f, v].
2. The novel stop consonants were [g, k].
3. The novel vowels were [æ, e].
4. Again following English restrictions, [æ] did not occur word-finally.

As in the familiarization phase, the arbitrary strings were created from the phonetically grounded strings reversing the order of C_1 and C_2 (see Table 1). As discussed in the following, each participant was exposed to both phonetically grounded and arbitrary stimuli during the test phase, although they had been familiarized with stimuli conforming to just one condition.[9]

[8]The fact that we included affricates may weaken the groundedness of the pattern, because a stop changing to an affricate is a less typical outcome intervocalically. For example, in the High German Sound Shift (Wright, 1907), *t became /s/ after a vowel and geminate *tt became /ts/ in the same position; but the affricate is also the word-initial outcome.

[9]In the test stimuli we introduced some new segments to expand on the familiarization inventory; they fall into a natural class with the familiarization segments, which are retained. We assume that children will normally define the observed patterns as broadly as possible, consistent with the data. The absence of a particular segment in the familiarization, such as [v], will not necessarily lead the child to formalize this absence (especially on the basis of few tokens) when the natural classes to which the absent segment belongs are attested in the pattern. That is, because [s, z, dʒ, tʃ] occur in a specific environment, the child will define the class with reference to the feature [continuant]; and lacking other evidence, such as the occurrence of [v] in the complementary context, will have no cause to delimit the class further (by referring to place of articulation, for example). When [f, v] are then introduced, they are predicted to pattern with the [continuant] class. In the future we will test, independently, whether the infant does in fact make these feature-based generalizations, but for now we hypothesize that they can and that for the infant the test stimuli that follow the familiarized pattern are the “same” in the relevant sense. Even if we were to assume that the infants were making phoneme-based, rather than feature-based, generalizations, in an Optimality Theoretic sense, the new patterned test stimuli would contain more violations than the familiarized patterned stimuli and hence we should expect the same results.

TABLE 1
Test Items for Experiment 1

Test Items	
Natural	*Unnatural*
gefæt kæve pasa	fegæt væke sapa
gosu dɛzo kæzɛt	sogu zɛdo zɛkæt
notʃæt dedʒo mæso	tʃonæt dʒedo sæmo
tizo bætʃa pofu	zito tʃæba fopu

Apparatus. The stimuli were digitized at a 20 kHz sampling rate and stored on a Macintosh G4 computer. The audio signal was then fed through a Yamaha audio amplifier to Cambridge Soundworks Ensemble II speakers.

The testing booth consisted of a 3-walled enclosure made of white pegboard panels, approximately 4.5 ft high, with white curtains that descended from the ceiling to meet the pegboard (see Figure 1). The pegboard was backed by thick white cardboard to cover the holes, except for one large and two smaller openings in the front panel. The larger opening allowed a camera to record the session. A smaller opening allowed the experimenter to view the infant's headturns. Finally, a third opening allowed a secondary observer, such as a second parent or grandparent, to view the procedure. A chair was placed in the center of the booth, facing the front panel.

A light was attached at the center of each panel, at the approximate eye level of an infant seated on a caregiver's lap in the chair. The light on the front panel was green, and the lights on the side panels were both red. Each of the two loudspeakers was situated behind the two side panels, located directly behind the red light. The computer, response box, and other equipment were located behind the front panel, out of sight of the infant.

Procedure. A modified version of the HPP (Jusczyk & Aslin, 1995; Kemler-Nelson et al., 1995) was used. Each infant was seated on the caregiver's lap on the chair in the middle of a small three-sided booth within a sound-attenuated testing room. The experimenter was situated behind the testing booth and observed the infant through the viewing hole. During the experiment, the orientation of the infant's gaze was recorded on the computer by means of a button box. All choices regarding the side light and specific auditory stimulus were made randomly via computer program. Both the experimenter and the caregiver wore tight-fitting headphones that played continuous music to mask the auditory stimuli the infant heard. The overhead light was dimmed to make the panel lights more salient.

During familiarization, both side lights in the testing booth flashed simultaneously and the auditory stimuli were played continuously out of both speakers be-

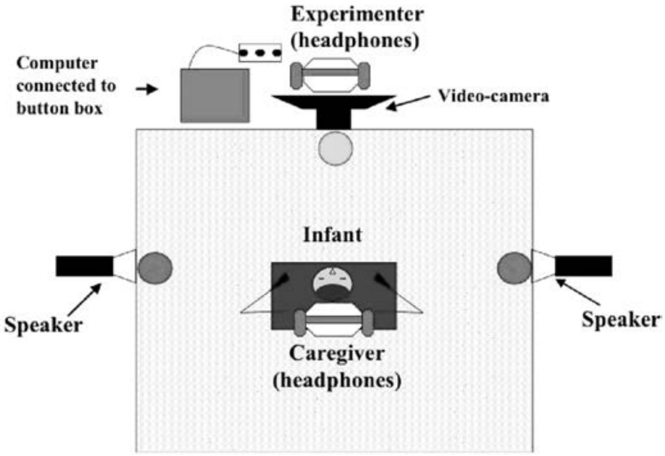

FIGURE 1 Diagram of the Headturn Preference Procedure (Jusczyk & Aslin, 1995).

hind the lights, and sound was noncontingent upon looking to the lights. Each test trial began with the central green light flashing to attract the infant's attention to the center. When the infant looked to the center light, this light would extinguish, and one of the two side red lights (chosen randomly by the computer program used to run the experiment) would begin to flash. When the infant oriented to the side light, one of the auditory test strings would play repeatedly. This continued until either the infant looked more than 30° away from the light for 2 consecutive sec, or the entire stimulus file was complete. (Each stimulus file consisted of a test string. There were eight stimulus test files in total, four phonetically grounded and 4 arbitrary, repeated a maximum four times with a 1-sec pause between each repetition.) At this point, the side light would extinguish, the sound would stop, and the front green light would begin to flash in preparation for the next trial. The computer recorded the amount of time the infant was looking toward the light while the stimulus was playing. If the infant looked away for less than 2 sec and then looked back again, the trial continued, but the amount of time spent looking away was not counted in the overall tally.

The infants in each group were familiarized with their respective lists of strings until they had accumulated at least 120 sec total listening time. This is the typical familiarization time period in previous statistical learning studies (e.g., Saffran et al., 1996). There were a total of 16 different familiarization strings for each group (each string separated by a 1-sec pause), repeated until the infant reached the 120-sec criterion; on average, each infant heard all of the familiarization strings approximately 2.75 times. The infants were then immediately presented with the eight different test word strings, presented in three blocks, for a total of 24 test trials. Because the test trials consisted of four repetitions of each of the test strings, depending on their orientation time to the light, the infants heard each string between 0 and 4 times per test trial. Because there were three blocks of 8 test trials (1 for each string), this means that the infant could hear each string a maximum of 12 times during the experiment. The order of presentation of the eight strings was randomized within each block. The dependent measure was the average looking time across trials to each stimulus type.

Results From Experiment 1

On average we found that, as with other statistical learning studies involving phonological rule learning (Chambers et al., 2003), the infants looked longer to stimuli that did not obey the familiarized rule—that is, a novelty preference (see Figure 2). Infants listened an average of 6.03 sec ($SE = 0.37$ sec) to stimuli that did not follow the rule and 5.27 sec ($SE = 0.34$ sec) to stimuli that followed the familiarized phonological rule. Seventeen out of 24 participants followed this pattern of preferring forms that violated the rule.

A three-way ANOVA—Block (block1/block2/block3) × Condition (phonetically grounded/arbitrary) × Familiarity (familiarized pattern/new pattern)—revealed a main effect of block, $F(2, 44) = 6.221$, $p < .0048$, a main effect of familiarity, $F(2, 44) = 6.76$, $p < .016$, and no main effect of condition, $F(2, 44) = .132$. There were also no interaction of block and condition, $F(2, 44) = .802$, no interaction of condition and familiarity, $F(2, 44) = .089$, and no interaction of block, condition, and familiarity, $F(2, 44) = 1.29$. The finding of a main effect of block was likely due to decreased listening times over the course of the experiment—infants listened an average of 5.91 sec on the first block, 5.8 sec on the second block, and 4.7 sec on the third block. These results are illustrated graphically in Figure 2.

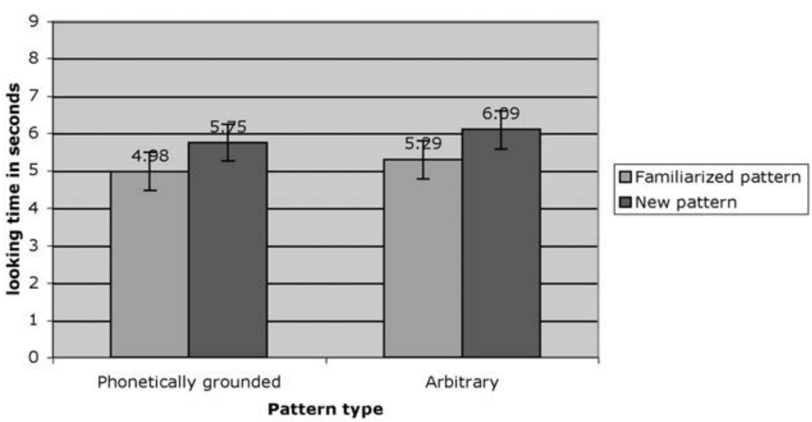

FIGURE 2 Graph of looking time preferences for Experiment 1.

Our primary interest was whether the phonetically grounded group would show better and more complete rule learning than the arbitrary group. The significant effect of familiarity and the lack of an interaction between familiarity and condition suggest that both groups learned the rule equally well. We further explored whether each group, by itself, demonstrated an effect of familiarity. Average looking times were calculated for each passage type for each familiarization group. On average, participants in the phonetically grounded group listened 4.98 sec (SE = 0.58 sec) to forms that followed the phonetically grounded rule and 5.75 sec (SE = 0.68 sec) to forms that violated it. Eight out of 12 participants in the phonetically grounded group looked longer to the form that violated the phonetically grounded rule (i.e., was a new pattern for that group). In the arbitrary group, participants listened 5.29 sec (SE = 0.49 sec) to forms that followed the arbitrary rule and 6.09 sec (SE = 0.50 sec) to forms that violated it. Nine out of 12 participants in the arbitrary group looked longer to the forms that violated the arbitrary pattern. *T* tests within the two familiarization groups revealed that neither of the groups (phonetically grounded and arbitrary) showed individually significant results for phonetically grounded, $t(11) = 2.187$, and for arbitrary, $t(11) = 1.02$; however, we believe that this lack of effect is due to the small sample size.

Discussion

In sum, we found that even young infants were (a) able to learn fairly subtle rules of manner feature distribution and (b) performed equally well at rule learning in the phonetically grounded and arbitrary conditions. We take this as evidence that it is possible for infants to learn arbitrary phonological rules and that infants are able to form categories based on certain phonological features, specifically continuants versus noncontinuants, to generalize to the novel words in the test phase.

An alternative interpretation of these findings is that infants merely recognized the initial stop–fricative distinction and disregarded the rest of the word in which the alternation occurred. That is, the generalization "initial consonants are noncontinuant" (or even the mere recognition of a fricative or affricate) could substitute for "intervocalic consonants are continuant." Regardless of the formal generalization, we have still shown that very young infants are sensitive to and are able to learn subtle manner distinctions.[10]

Even though we found evidence for some sort of phonological rule learning, we wished to test whether this phonological rule learning could be extended to more complicated rules that cannot be localized to one segment alone. For this reason, in

[10]This is similar to the sensitivity Swingley and Aslin (1999) showed in 18- to 24-month-olds; however, unlike Swingley and Aslin's study, ours does not involve word learning.

our next experiment we exploited a rule that did not rely solely on the initial phoneme. To extend our findings to different types of phonological rules, this study also used a rule of place rather than manner.

EXPERIMENT 2

In Experiment 1, we focused on infants learning a rule concerning continuancy (fricatives vs. stops), a manner feature. In Experiment 2, we focused on learning of a rule that deals with place features. Although the rules in Experiment 2 were more complicated than the rules in Experiment 1 because they involved a dependency between two segments (specifically, a vowel and its preceding consonant did or did not share the same place), we have ample evidence that children are sensitive to place from quite early on. For example, Jusczyk and Aslin (1995) showed that 8-month-old infants can perceive the difference between *dog* and a similar yet unfamiliar word, *bog*. Although Stager and Werker (1997; Werker, Fennell, Corcoran, & Stager, 2002) concluded that in tasks involving two unfamiliar words 14-month-old infants do not seem to be able to represent this level of phonetic detail and cannot differentiate between *bih* and *dih*, recently Fennell and Werker (2003) provided evidence that 14-month-old infants are sensitive to mispronunciations of words that change the place feature of a word's initial phoneme (*goll* vs. *doll*). Findings of a predisposition or preference for consonant–vowel harmony systems in early production have been found (e.g., Levelt, 1994), thus lending further credence to the idea that the sort of harmony to be exploited in Experiment 2 is grounded. Clearly, though, with respect to a task such as ours (and Jusczyk & Aslin, 1995), which does not involve naming, infants are able to discriminate place differences; thus in Experiment 2 we explore two rules concerning place.

In Experiment 2, we also removed a confound present in Experiment 1: Although in Experiment 1 it was possible to argue that infants had responded to only the first phoneme of a word (whether it was a stop or a continuant), in Experiment 2, infants had to learn an assimilation pattern that concerned the relation between the two initial phonemes of a word.

In this study, infants learning the phonetically grounded pattern were familiarized with words in which the first consonant and vowel have the same place of articulation, grouping together labial consonants (*v, p, m*) with round vowels (*o*, *u*) and alveolar consonants (*s*, *d, n*) with front vowels (*i, e*)—for example, *vogo sidu pova*. We considered these to be unmarked, phonetically grounded patterns because they are found in many of the world's languages, for example, Cantonese (Flemming, 2003) and Maltese (Hume, 1996; see also Flemming, 2003) and are phonetically conditioned by use of the same articulator. Infants learning the arbitrary pattern were familiarized with forms in which the first consonant and vowel do not share place features; instead, their stimuli had an arbitrary correlation of labial consonants (*v*, *p, m*) with high vowels (*i*, *u*) and coronal consonants (*s*, *d, n*) with mid vowels (*o*, *e*)—for example, *vigo sodu piva*. We considered this pattern marked and arbitrary because it is unattested to our knowledge and is not phonetically conditioned. Infants were tested on novel word forms that either obeyed the familiarized grammar's patterns or violated them (e.g., phonetically grounded, *degi boki zita*, and arbitrary, *degi biki zota*). As in Experiment 1, we examined the ambient language to make sure that ambient frequency was not a confound in our experiment. Searches of the Switchboard speech corpus of English (Godfrey, Holliman, & McDaniel, 1992) revealed that CVCV words with the grounded (front–round) pattern had a lexical frequency count of 287 and CVCV words with the arbitrary (high–mid) pattern had a count of 267. Given that these two patterns showed fairly similar frequency distributions, we concluded that the infants would not likely be influenced by the ambient language.

Method

The same method was used as in Experiment 1, except that in Experiment 2 infants were familiarized for 4 (rather than 2) min. We included a longer familiarization phase because a pilot study indicated that these rules were harder for the infants to learn. Because of the longer familiarization time, it was more likely that the infants would become bored with the study. To prevent infants from getting too bored, we included lights that were contingent upon infants' looking. This also makes this second study more similar to the study presented in Chambers et al. (2003) because they also used contingent lighting.

Participants

We tested 35 infants from monolingual English-speaking households in the West Lafayette area in the infant lab at Purdue University. Thirteen infants were excluded from the final analyses for the following reasons: crying or fussing (8), wiggling and seeming distracted by the parent and failing to look at any test stimulus for an average of more than 2 sec (4), and experimenter error (1). The data from the remaining 22 participants was analyzed; 13 were girls, and 9 were boys. These infants were an average age of 9 months and 7 days (range = 8 months, 24 days to 9 months, 14 days) and were primarily from middle class households. Eleven infants were assigned to each experimental condition.

Stimuli

As with the previous experiment, both familiarization and test stimuli followed certain constraints. In the familiarization stimuli the constraints on the first syllable were as follows:

1. The only stops used were [p, d].
2. The fricatives used were [v, s].
3. The nasals used were [m, n].
4. The vowels used were [ɪ, u, e, o].

A spreadsheet program was used to generate random new words within this language. In the schema $C_1V_1C_2V_2$, the first consonant (C_1) was randomly determined to be either labial or alveolar; the specific consonant was then randomly chosen from the restricted sets [p, v, m] (labials) or [d, s, n] (alveolars). The following vowel (V_1) was randomly chosen from the phonetically grounded (round or front) correlation set, thus [u, o] after a labial or [ɪ, e] after an alveolar.

In the second syllable, the only stops used were [b, p, d, t, g, k], the fricatives used were [v, f, z, s, ʃ], the only nasals used were [m, n], and the only vowels used were [i, u, e, o, a]. The contents of the final syllable (C_2V_2) were generated randomly from all the vowels and consonants shown (including [b, t, k, g, f, z, ʃ, a]), with no dependency between the C and V. To cancel any chance biases in the frequency of specific consonants or vowels in the first syllable, or the nature of the second syllable, the arbitrary familiarization set was generated directly from the phonetically grounded set by swapping the vowels [i] and [o] in V_1 position, yielding the labial–high and coronal–mid correlation. (Because [e] and [u] were not swapped, the correlation of vowel frontness with consonant place was eliminated in favor of the arbitrary height correlation.)[11]

As in the previous experiment, words judged similar to common vocabulary items of English were dropped and replaced by other random words, and all words were pronounced with trochaic stress. We adopted a rule that only occurred in the first syllable of the word (as opposed to the whole word or second syllable) to simplify learning of the rule for infants and because there is considerable evidence that infants pay more attention to the beginnings of words than the ends of words (Houston, Jusczyk, & Jusczyk, 2003; Jusczyk, Bauman, & Goodman, 1999) and to the stressed syllable of a word (Jusczyk, Houston, & Newsome, 1999). In addition, by locating the rule in only one syllable we avoided making stimuli that were too monotonous and would bore the infants.

[11]We did not swap [e] and [u] as well as [i] and [o] because the output would not have resulted in high–mid as the new categories, but rather a simple reversal of the front–round condition. This might have been perceived as dissimilation along natural dimensions, rather than unnatural pseudo-assimilation between high–labial and mid–alveolar.

Familiarization (phonetically grounded strings):
vogo puta vude, puso sidu senu, dedu segi diki, nepi diʃe sike, vuzu siti vosu, voʃa muki motu, vulo moli seko, pova sezo vofo, mupi vuta nebi, dite vuzo degu, vufo sige votu, deʃi vulu putu, diva nebe dife, vozu nepi dile, nene sefi sisu, puma nelu dimo, deki pozo nile

Familiarization (arbitrary strings):
vigo puta vude, puso sodu senu, dedu segi doki, nepi doʃe soke, vuzu soti visu, viʃa muki mitu, vulo mili seko, piva sezo vifo, mupi vuta nebi, dote vuzo degu, vufo soge vitu, deʃi vulu putu, dova nebe dofe, vizu nepi dole, nene sefi sosu, puma nelu domo, deki pizo nole

As with Experiment 1, in the test phase of Experiment 2 we added four novel consonant phonemes to the initial position, specifically [b, t, f, z]. These forms were generated randomly according to the same procedure used for the familiarization stimuli. To assure generalization of the rule instead of memorization of a particular form, no word from the familiarization occurred in the test phase (see Table 2).

Results From Experiment 2

Overall, infants listened an average of 7.26 sec (*SE* = 0.11 sec) to stimuli that did not follow the familiarized rule and 6.06 sec (*SE* = 0.09 sec) to stimuli that followed the familiarized phonological rule (see Figure 3). Sixteen out of 22 infants followed this pattern of listening longer to the new forms over the familiarized forms.

A three-way ANOVA—Block (block1/block2/block3) × Condition (phonetically grounded/arbitrary) × Familiarity (familiarized pattern/new pattern)—revealed that there was no main effect of condition (phonetically grounded/arbi-

TABLE 2
Test Items for Experiment 2

Test Items	
Natural	*Unnatural*
degi boki fuʃi	degi biki fuʃi
zita fupu teʃe	zota fupu teʃe
voka tika ziʃu	vika toka zoʃu
mume timu folu	mume tomu filu

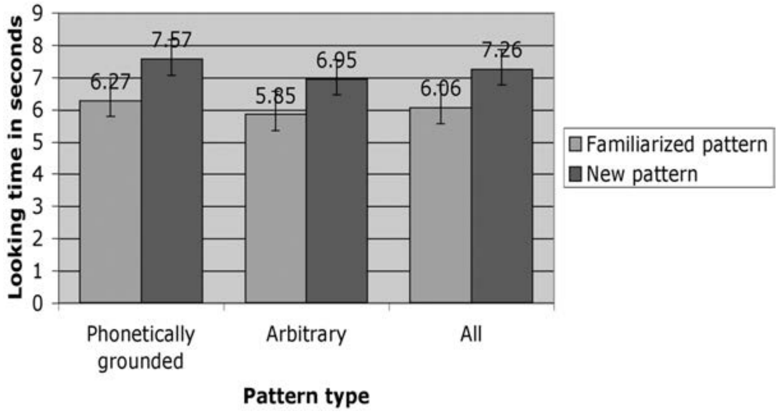

FIGURE 3 Graph of looking time preferences for Experiment 2, Block 1.

trary), $F(2, 40) = .081$, no interaction of block and condition, $F(2, 40) = .302$, no interaction of condition and familiarity, $F(1, 20) = 2.01$, and no interaction of block, condition, and familiarity, $F(2, 40) = .451$, but a significant effect of block, $F(2, 40) = 9.63$, $p < .0004$, and an interaction of block and familiarity, $F(2, 40) = 5.78$, $p < .006$. Given that there was no main condition effect and no interactions with condition, the rest of the data we report will collapse across conditions.

Because of the significant Block × Familiarity interaction, we also looked at whether the infants showed a differential preference for the familiarized patterned word or new patterned words across the blocks of the experiment. Post-hocs revealed that in the first test block, infants displayed a clear novelty preference;[12] that is, they listened longer to the new patterned word strings (7.26 sec) than to the familiarized ones (6.06 sec), $t(21) = 8.14$, $p < .006$. In both the second, $t(21) = 1.92$, and third test blocks, $t(21) = -.688$, there was no clear preference for familiarized or new forms. We believe that this result was due to the length of our experiment—beyond the attention span of the infants—and so the remainder of the results we show are only from this first block.

[12]Chambers et al. (2003) actually found a familiarity preference for their more complicated rule (or second order rule). One possible reason that we still found a novelty preference is that our familiarization period was much longer, so that the infants became more habituated to the rule. Another possible reason is that our rules are simpler to learn than theirs because they are amenable to phonological generalization according to classes such as "labial" and "front," whereas in their study the infants had in fact to learn arbitrary classes such as [b, k, m, t, f]. Saffran and Thiessen (2003) also suggested that sound patterns that do not form a natural class (such as the ones presented in Chambers et al., 2003) are harder to learn than sound patterns associated with natural classes and that these more difficult patterns result in familiarity, as opposed to novelty preferences.

Because we were primarily interested in whether infants in the phonetically grounded group performed differently than those in the arbitrary group, we also calculated looking times within group for the Block 1 trials. *T* tests revealed that neither of the groups (phonetically grounded and arbitrary) showed individually significant results, $t(10) = -2.56$, for phonetically grounded and, $t(10) = -1.80$, for arbitrary, however, we believe that this lack of effect may be due to the small sample size. Although the group who heard the phonetically grounded rule had longer listening times, there was no significant difference between the two groups, $t(10) = .265$.

Discussion

In sum, our results in Experiment 2 mimic our results from Experiment 1. The infants were able to learn the rule in both the phonetically grounded and arbitrary conditions and preferred to listen to new patterned words over familiarized patterned words in Block 1, immediately following familiarization.

It is obviously out of the question to expose infants solely to an artificial language over a period of months to see whether they successfully can acquire the patterns in a manner that resembles normal acquisition. We do, however, have the evidence of "natural experiments" from the hundreds of natural languages whose phonologies have been studied by linguists. These natural languages were acquired by children, of course, and the presence of phonetically arbitrary patterns in these languages shows that such patterns are eminently learnable. In fact, it has long been observed that phonological rules tend to become less phonetically grounded over time—what Hyman (1975) called "the great tendency for rules to become unnatural … that is, to lose their phonetic plausibility and become morphologically conditioned" (p. 81). Despite this prima facie evidence against a strong bias for phonetically grounded rules, most phonological theories attempt to encode naturalness or markedness; for recent criticism of incorporating phonetic groundedness in phonological theory, see Hale and Reiss (2001), Buckley (2003), and Blevins (2004). On the other hand, Jusczyk et al. (2002) argued that even under brief exposure to artificial language stimuli, a bias toward a phonetically grounded pattern of nasal assimilation can be detected in young infants.

As in many of the empirical studies cited here, including Jusczyk et al. (2002), we have assumed that brief exposure to carefully designed stimuli can give us a glimpse of the learning mechanism that children use in acquiring their native language. The results of our two studies imply a learning mechanism that looks for and is able to learn patterns regardless of their phonetic grounding. Although we assume that there are certain universal and innate tendencies of the language learning mechanism (such as the ability to find natural classes), this evidence (and other evidence from statistical learning) also supports a language learning mechanism in which the potentially arbitrary input plays a large role in language learning.

Conclusions

It also seems that infants in these experiments were able to learn both phonetically grounded and arbitrary rules. There are a few reasons why this might have been the case. First, one could claim that our arbitrary rules were not arbitrary enough—if they had been more arbitrary, then possibly infants would have had more trouble learning them. This issue is very much dependent on the formalization of phonetic groundedness in a specific phonological theory, and the degree of phonetic groundedness is not something we are able to address with these data. Second, it may be that we presented languages in such idealized conditions that the infants could learn even the arbitrary rules, but under more ecologically valid conditions we would have seen more of a difference.

Clearly infants have a sense of phonological features even before they utter their first word. Knowledge of phonological features is a prerequisite for the acquisition of the phonological patterns present in one's language, because if the child were unaware of featural commonalities among segments, it would be quite difficult to come up with the correct generalizations or groupings present in the input language. Our data from the learning of phonological patterns speaks to the infants' early awareness of phonological features. In addition, Saffran and Thiessen's (2003) recent studies have shown an early awareness of phonological features—specifically of voicing. In these studies they show that phonotactics acquired during an experiment may influence segmentation in 9-month-old infants. The infants in these studies were familiarized with words that followed a certain pattern and then confronted with uninterrupted strings of speech that either conformed to words of the familiarized phonotactic pattern or did not. In their first experiment, infants were familiarized with either a CVCV pattern or a CVCCVC pattern. The infants in this study listened longer to the lists that were consistent with the familiarized pattern (a result which could be interpreted as priming rather than learning of a phonotatic pattern). In their second experiment, infants were familiarized with a restriction on the syllable position of voiced and voiceless consonants. One group was familiarized with words in which voiced stops were in onset position, and voiceless stops were only in coda position, and the other group heard the opposite pattern—voiceless stops in onset position and voiced stops in coda position. In this experiment, both groups of infants listened longer to lists that were inconsistent with the familiarized lists (a result that could not be interpreted as mere priming). This second experiment also reveals a finding similar to ours in comparing a fairly phonetically grounded pattern of voiceless stops in coda position with a relatively arbitrary condition where only voiced stops occur in coda position. Saffran and Thiessen (2003), however, faced the same confound that we have in our first experiment. Namely, it could be that the infants in their experiment only observed the voicing of the consonants in onset position and did not notice the coda differences at all. It seems that infants in these studies were able to make use of featural similarity in their generalization of the familiarized rules. This suggests that even infants as young as 9 months have started to group the phonemes of their language into natural classes.

This is not to say that infants' meager lexical representations are fully specified for all phonological features. That is, as previously mentioned, one way of thinking about phonological acquisition is in a movement from less specification to more specification. This is the perspective supported by Metsala and Walley (1998), among others. The other mode of thinking (e.g., Gnanadesikan, 1995; Smolensky, 1996) is that infants begin with structure and simply reorganize that structure in accordance with the input. Even though our data clearly show an early awareness of phonological features such as [round] and [front], we do not show anything about the representation of such features in the lexicon. We do, however, believe that such features must be present in some way in the infant brain for the infant to generalize from the forms in familiarization to the novel forms and novel segments presented in the test phase of our experiments. In addition, there is considerable evidence that young children's representations are mostly, if not entirely, specified (Swingley, 2003; Swingley & Aslin, 2000, 2002).

We have described the phonotactic patterns in these experiments—such as restrictions on the occurrence of stops in intervocalic position—as "rules," which might be objectionable in two ways. First, in OT (Prince & Smolensky, in press), there are no rules that define specific changes to a representation; rather, a constraint ranking determines the preferred output forms, and changes are made, if necessary, to bring an output into conformity. For our purposes this is just a matter of terminology, because rules and constraint rankings are both intended to analyze phonological alternations. The second potential objection is that the generalizations to which the children are exposed reflect static facts about the distribution of segments: phonotactics rather than alternations.[13] It is a standard view in phonological theory, however, that generalizations about phonotactics are formally related, perhaps identical, to generalizations that capture active alternations. Failure to unite these generalizations is the Duplication Problem (Kenstowicz & Kisseberth, 1977), and unifying them is one of the basic goals of OT. We feel justified, therefore, in using the perception of static generalizations by young infants as a stand-in for the learning of alternations that depend on morphological knowledge. This position may be essential, in fact, for any study of rule learning at such a young age; contrast the problems with the model used to study alternations in Jusczyk et al. (2002), discussed in "Previous Research" section.

[13]We feel that the further questions raised regarding how rankings are sensitive to social context, and how they are integrated into existing rankings, are quite important for a complete theory, but well beyond the scope of this study.

Finally, our results lead us to question the findings from production that suggest a preference for grounded structures. It may be that infants' difficulty producing articulatorily more complex segments or sequences is due to their immature articulators, and does not necessarily indicate a different grammar for adults and infants. We suspect that the infants' grammar (or the initial state of the infant grammar) closely resembles the adult grammar (as suggested by Hale & Reiss, 1998, 2001) and that it is not differently structured as suggested by Smolensky (1996). This grammar seems to be unbiased towards the input and can easily learn grounded and ungrounded patterns: We specifically designed our experiments to minimize the effect of articulatory difficulty and thereby to examine the phonological capacity independent of physical limitations. This absence of bias is supported by the fact that adults have learned and maintained the ungrounded structures in their grammars, and the child grammar is usually more, not less, flexible than the adults'.

In future work, we will explore more about the nature of the early state of the grammar. First, we will test a broader range of arbitrary rules, including varying degrees of arbitrariness, to the extent that this can be gauged in a consistent way. Second, we will look in more detail at the phonological features that infants are able to use to form natural classes. For example, will they be able to extract features and learn rules that involve features that are not contrastive in the ambient language? Third, we will continue to compare a phonetically grounded and an arbitrary rule within the same experiment to see if infants find one type easier to learn. The partial results from Experiment 2 suggest that although arbitrary rules are learnable, infants may favor the phonetically grounded rule in the test situation; but more careful study is required to arrive at a more secure answer to this important question.

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