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Infants generalize from just (the right) four words

LouAnn Gerken*, Sara Knight

The University of Arizona, United States

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ABSTRACT

Infants in the lab can generalize from 2 min of language-like input. Given that infants might fail to fully encode so much input, how many examples do they actually need? And if infants only encode a subset of their input at one time, does generalization change when that subset supports multiple generalizations? Exp. 1 asked whether 11-month-olds generalize the relation between two consonants in a word when just four input words provided non-conflicting vs. partially conflicting support for a phonological feature-based generalization. Infants learned under both conditions, although the latter appears to be more difficult. Exp. 2 asked whether infants' robust learning reflects a bias toward feature-based generalizations. Infants failed to generalize when input provided completely conflicting support for two generalizations. Together, the data suggest that infants are able to generalize from much less input than previously observed, but generalization depends on the specific subset of the input they encounter.

1. Introduction

One of the most exciting findings from the past two decades of research with infants is that they can make generalizations about the structure of language-like input from 2 min of laboratory exposure to a dozen or more examples (e.g., Chambers, Onishi, & Fisher, 2003; Gerken, 2006, 2010; Gerken, Wilson, & Lewis, 2005; Gómez & Gerken, 1999; Gómez & Maye, 2005; Koulaguina & Shi, 2013; Marcus, Vijayan, Rao, & Vishton, 1999; Saffran & Thiessen, 2003; Seidl & Buckley, 2005). Although two minutes of input seems very short compared to the hundreds of hours that infants are exposed to language in the real world, it is nevertheless possible that infants in the lab and in the real world fail to attend to or encode all of the input examples in even a relatively short language-learning opportunity. Therefore, it seems possible that infants can in fact generalize from many fewer input examples than we typically employ in infant language-learning experiments in the lab. The main goal of the current experiments was to see if infants could generalize from just four words.

If infants in fact encode just a subset of laboratory input that has been carefully constructed to support a particular linguistic generalization, it is also possible that the subset they encode supports multiple possible generalizations. Of course, it has long been acknowledged by language researchers that *any* input set can support an infinite number of generalizations, which is a reason that innate constraints on generalization have been proposed (e.g., Chomsky, 1965). Nevertheless, it is possible to ask how generalization is affected when the input supports one vs. two generalizations that infants have previously been shown to make: phonetic features and particular consonants (e.g., Chambers et al., 2003; Saffran & Thiessen, 2003). Thus, the second goal of the current experiments was to compare infants' generalization from four words that support only a feature-based generalization or a feature-based and a consonant-based generalization.

With respect to this second goal, consider the four nonwords 1a–d. The two consonants contained in each of the

* Corresponding author at: Department of Psychology, The University of Arizona, Tucson, AZ 85721-0068, United States.
E-mail address: gerken@email.arizona.edu (L. Gerken).

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words share the same value of the phonological feature voicing (*d/v*, voiced; *p/t*, voiceless). In addition though, pairs of words share particular consonants (i.e., two instances of *p/t* and two of *d/v*). If linguistic generalization typically involves some comparison across two or more input items to determine what they have in common (Gerken, Dawson, Chatila, & Tenenbaum, 2014), pairs of words that share particular consonants might lend support to a generalization that involves consonants in addition to one involving features. Because the words in 1a–d all support a feature-based generalization, but also partially support a consonant-based generalization, these words compose the *Partially Conflicting Condition* of Exp. 1.

1a. dova
1b. pota
1c. pata
1d. dava

Now consider the four nonwords 2a–d. These words also all contain two consonants that share the same value of the phonological feature voicing. They were chosen to avoid pairs of words that share consonants or other properties that might compete with a phonological feature- based generalization. Because, of the two types of generalization being manipulated here, the words in 2a–d only support the feature-based generalization, these words compose the *Non-Conflicting Condition* of Exp. 1.

2a. pota
2b. tapa
2c. biza
2d. deva

Exp. 1 asked whether infants could generalize from four input words, and if they can, do they show different patterns of generalization for the Partially Conflicting and Non-Conflicting input conditions? If infants generalize in either condition, we will have evidence of more rapid learning than has been previously observed in experiments where the pre-test input contains many more than four items. To foreshadow, infants learned in both conditions of Exp. 1; therefore Exp. 2 employed a Completely Conflicting Condition to determine if the learning found in Exp. 1 was based on a bias toward feature-based over consonant-based generalizations.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Participants were 36 infants from English-speaking homes, ranging in age from 10.7 to 11.7 mos, with a mean of 11.1 mos. We chose to study 11-month-olds, because our task involves learning new phonotactic generalizations, and previous studies have shown successful learning of such generalizations by 9-month-olds (Saffran & Thiessen, 2003) and 16-month-olds (Chambers et al., 2003). Pilot testing with 9-month-olds with a larger number of input stimuli revealed learning only in girls, therefore, we moved to a slightly older age group.

Eighteen infants (8 females) were in the Partially Conflicting Condition and 18 (10 females) in the Non-Conflicting Condition. All infants were at least 37 weeks to term, at least 5 lbs 8 oz at birth, had no history of speech or language problems in their nuclear family, and were not given medication for an ear infection within one week of testing. Four additional infants were tested but not included because they either fussed during pre-test or test (1 Partially Conflicting, 2 Non-Conflicting) or had overall listening times more than 2SD above the mean (1 Non-Conflicting).

2.1.2. Materials

Materials for Exp. 1 are the pre-test words shown in the Partially Conflicting and Non-Conflicting rows of Table 1. Pre-test words were always four consonant–vowel–conso

Table 1
Pre-test words for voicing and place of articulation rules. The first two experimental conditions were employed in Exp. 1 and the third in Exp. 2. Test items for all infants in all conditions were the same reflecting the voicing rule on some trials and the place of articulation rule on other trials. Voicing rule test items were: *deba, tafa, bida, posa, tifa, beda, pasa, doba*. Place of articulation test items were: *deta, tada, bifa, pova, tida, befa, pava, dota.*

Exp. Condition	Rule:	Pre-test words	Possible competing generalization(s)
Exp. 1 Partially Conflicting All words support feature-based rules and some words support consonant-based rules	Voicing rule (½ of infants)	*dova*, *pota*, *pata*, *dava*	Consonants share voicing vs. Consonants are d/v, Consonants are *p*/*t*
	Place rule (½ of infants)	*poba*, *dosa*, *dasa*, *paba*	Consonants share place of articulation vs. Consonants are *p*/*b*, consonants are *d*/*s*
Exp. 1 Non-Conflicting All words support feature-based rule	Voicing rule (½ of infants)	*pota*, *tapa*, *biza*, *deva*	Consonants share voicing
	Place rule (½ of infants)	*poba*, *taza*, *bipa*, *desa*	Consonants share place of articulation
Exp. 2 Completely Conflicting All words support both feature-based and consonant-based rules	Voicing rule (½ of infants)	*pota*, *pata*, *pita*, *peta*	Consonants share voicing vs. consonants are *p*/*t*
	Place rule (½ of infants)	*peba*, *paba*, *poba*, *piba*	Consonants share place of articulation vs. Consonants are *p*/*b*

nant–vowel (CVCV) nonwords. For half of the infants in each condition, the two consonants shared the same voicing value (both voiced or voiceless), and for the other half, the consonants shared the same place of articulation (both labial or coronal). For infants in the Partially Conflicting Condition, the nonwords all supported a feature-based rule (voicing or place of articulation), but pairs of words also supported a rule based on particular consonants. For infants in the Non-Conflicting Condition, no two words contained the same consonants in the same order.

The test items were the same for all infants and on different trials were eight new words that were consistent with the voicing generalization and eight new words that were consistent with the place of articulation generalization (see Table 1). Two random orders of each set of test words were created, yielding four different test trials. Infants participated in three blocks of the four trials, for 12 test trials in total. None of the test words contained the consonants shared by pairs of words in the Partially Conflicting Condition (*d/v, p/t, p/b, d/s*); therefore any generalization at test must be feature-based, not consonant-based.

2.1.3. Procedure

The headturn preference procedure (Kemler Nelson et al., 1995) was used. Infants were seated on a parent's lap in a small room. The parent listened to pop music through headphones in order to mask the stimuli heard by the infants and prevent inadvertent influence on the infant. During the pre-test phase, a light directly in front of the infant flashed until the observer, blind to the experimental condition and unable to hear the stimuli, judged the infant to be looking at it, at which point a light on the left or right would begin flashing. When the infant looked first at the side light and then away for two consecutive seconds, the center light would resume flashing, and the cycle would begin again. This continued for the duration of the pre-test stimulus, which played uninterrupted to its conclusion. In this stage there was no correspondence between infants' looking behavior and the stimuli. Because the four pre-test words only played for about 4.5 s, they were preceded by about 1.5 min of Andean instrumental music to allow infants to become accustomed to the testing booth and procedure.

After the pre-test sequence ended, the test phase began immediately. The flashing lights behaved the same way except that now the sound was contingent on the infant orienting to a side light. Each time a side light began flashing and the infant oriented toward it, one of the four test trials would play, continuing until either the infant looked away for two consecutive seconds or the test trial reached its conclusion. Test words were played for as long as infants looked in the direction of the speaker playing the words. Test trials shorter than 2 s were excluded from the analysis.

2.2. Results

Infants' mean listening times in seconds to test trials that conformed vs. failed to conform to their pre-test rule (voicing or place of articulation) were subjected to a 2 pre-test condition (Partially Conflicting vs. Non-Conflicting) × 2 rule type (voice vs. place) × 2 test item conformity (conforming vs. nonconforming with pre-test words) ANOVA (see Fig. 1). There were no significant main effects (all F's < 1). However, there was a significant interaction between pre-test condition and test conformity ($F(1,32) = 10.95$, $p < 0.01$). Because none of the other interactions approached significance (all F's < 1), planned *t*-tests were used to ask whether infants showed learning in the Partially Conflicting and/or Non-Conflicting Conditions. Infants in the Partially Conflicting Condition listened significantly longer to conforming test items (mean conforming = 7.53, SE = .49; mean non-conforming = 6.53, SE = .41; $t(17) = 2.66$, $p < 0.01$; $d = 0.52$; 14/18 showed a familiarity preference). Infants in the Non-Conflicting Condition listened significantly longer to the non-conforming test items (mean conforming = 6.50, SE = .54, mean non-conforming = 7.61, SE = .40; $t(17) = 2.22$, $p < 0.05$; $d = 0.54$; 13/18 showed a novelty preference).

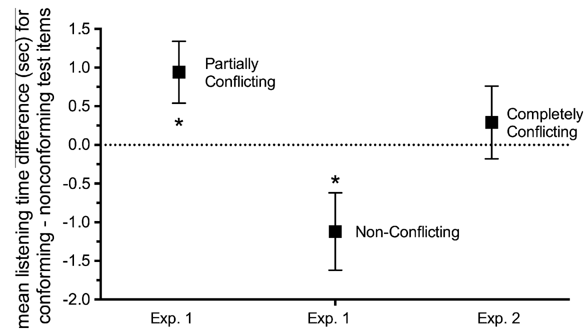

Fig. 1. Listening time differences (and standard errors) for test items that conformed vs. failed to conform to a phonological feature rule (voicing or place of articulation), depending on experimental condition (see Table 1). Listening time differences significantly above (familiarity preference) or below (novelty preference) the 0 line indicate significant learning of the rule (indicated by ∗).

2.3. Discussion of Exp. 1

Exp. 1 revealed two important findings. First, 11-month-olds were able to generalize a rule like those found in natural language (Rose & Walker, 2004) from only four input words. This learning is more rapid than any that has been heretofore observed in laboratory studies of infant language learning that we know of.

Second, although infants in both conditions generalized, infants who received Non-Conflicting input showed a novelty preference, while infants who received Partially Conflicting input showed a familiarity preference of approximately the same magnitude. A number of infant cognition studies indicate that robust pre-test generalization causes infants to attend more to the non-conforming test items than to the conforming test items (novelty preference), while less robust pre-test generalization causes infants to attend more to the conforming test items (familiarity preference) (Aslin, 2007; Gerken et al., 2014; Hunter & Ames, 1988; Hunter, Ames, & Koopman, 1983). Such findings suggest that infants in the Partially Conflicting Condition may have made a less robust generalization than infants in the Non-Conflicting Condition. This interpretation of the data is consistent with our suggestion that infants in the Partially Conflicting Condition made non-feature-based generalizations as well as the appropriate feature-based generalization, with the latter "winning."

Three alternate interpretations counter our view that learners in the Non-Conflicting Condition made both feature- and non-feature-based generalizations. One alternative concerns *variability matching between input and test*. The Non-Conflicting Condition contained four different pairings of the first and second consonants (C_1 and C_2), while the Partially Conflicting Condition contained only two different pairings. The test items contained four different pairings. On this view, infants might have learned equally well in both conditions, but the increasing mismatch between input and test variability leads from novelty to familiarity at test.

Another alternative is that *more variability in the input leads to more robust learning*. If we think of C_1C_2 pairings as input types, a number of previous studies have shown better generalization from more input types but not more tokens of a type (e.g., Gerken & Bollt, 2008; Xu & Tenenbaum, 2007). Thiessen and Pavlik (2013) provide an alternate input variability-based mechanism to type/token differentiation: Greater variability means that irrelevant stimulus properties (such as particular consonants) contradict each other. It is important to note that all of the preceding accounts of the listening time differences between the conditions of Exp. 1 assume that the infant makes a feature-based generalization.

Another possible explanation for the difference in looking behavior at test might be that the input in the Non-Conflicting Condition had more non-featural (e.g., consonant) overlap with the test items than the Partially Conflicting Condition. That is, infants were generalizing based on particular consonants, not features. We find this explanation unlikely for three reasons: First, none of the test items shared any C_1C_2 pairings with the input items. Second, although there was more overlap between C_1s of the Non-Conflicting Condition (*p t b d*) than the Partially Conflicting Condition (*p d*) with test items (*p t b d*), the same C_1s appeared in the test items for *both* rules. Finally, the test items for each rule contained two C_2s that *never* occurred in any of the input items (*f d*), while the other two test item C_2s occurred in both input conditions for the *opposite* rule. That is *v t* occurred as C_2 for both input conditions of the voicing rule and in the test items of the place rule, while *b s* occurred as C_2 in both input conditions of the place rule and in the test items of the voicing rule. In short, the data from Exp. 1 suggest that infants generalized based on phonological features during the input phase.

One remaining question is whether the infants in Exp. 1 were biased, either innately or based on exposure to English to weigh feature-based generalizations more heavily than generalizations based on particular consonants (e.g., Chomsky, 1965; Prince & Smolensky, 1997; Wilson, 2006). Thiessen and Pavlik (2013) also suggest that input "variability will be less beneficial when the abstraction parameter is set to a lower value," which we take to mean that their explanation for the novelty vs. familiarity preference in Exp. 1 depends on weighting the more abstract generalization (features) higher than the less abstract one (consonants). In support of such a bias or weighting difference, Saffran and Thiessen (2003) found that infants were better able to learn a phonological feature-based grouping of consonants than an arbitrary grouping. Further, recent findings indicate that the brain is more highly tuned to the acoustic manifestations of phonological features than to particular consonants and vowels (Mesgarani, Cheung, Johnson, & Chang, 2014). We take infants' different listening preferences in the two conditions of Exp. 1 to suggest that infants in the Partially Conflicting Condition did consider non-feature-based generalizations. And, several studies have shown that infants are able to learn consonant-based rules when these rules are not in conflict with feature-based rules (Cristià, Seidl, & Gerken, 2011; Gerken & Bollt, 2008; Seidl & Buckley, 2005). However, a stronger test of a feature bias might be to present infants with a *completely conflicting* input set that pits feature-based rules against consonant-based rules. If infants are strongly biased toward feature-based rules, they should generalize these over consonant-based rules when the two completely conflict. In contrast, if any feature bias that infants might have can be overcome by the evidence of the input, they should not show learning if the input is completely conflicting. Exp. 2 contrasted these possibilities.

3. Experiment 2

3.1. Methods

3.1.1. Participants

Participants were 18 infants (9 females) aged 10.6 to 11.6 months and of the same demographic as the infants in Exp. 1. Four infants were excluded for fussiness.

3.1.2. Materials

Materials are shown in the Completely Conflicting row of Table 1. Each pre-test word conformed to either the voicing or place of articulation rule, as well as sharing both consonants with all of the other pre-test words. The test words were identical to those in Exp. 1.

3.1.3. Procedure

Infants were tested using the same procedure as in Exp. 1.

3.2. Results

A *t*-test revealed no significant difference in listening times at test (mean conforming = 6.82, SE = .44; mean non-conforming = 6.53, SE = .56; $t(17) < 1$; $d = 0.14$; 10/18 listened longer to conforming test items. See Fig. 1).

3.3. Discussion of Exp. 2

When the entire four-word input supported both phonological-feature-based generalization and a consonant-based generalization, the 11-month-olds in Exp. 2 failed to show any evidence of learning. This failure stands in contrast to the two conditions of Exp. 1 and suggests that infants are not sufficiently biased toward a feature-based generalization to override completely conflicting evidence for a non-feature-based generalization.

One of the alternate explanations we raised with regard to Exp. 1 is still in play for Exp. 2: The *variability matching between input and test* explanation focuses on the fact that the Non-Conflicting Condition of Exp. 1 had four different C_1C_2 sequences, the Partially Conflicting Condition had two, and the Completely Conflicting Condition of Exp. 2 had one. On this view, infants might have learned equally well in all three conditions, but the increasing mismatch between input and test variability leads from novelty, to familiarity, to no preference at test. As noted with respect to Exp. 1, the significant learning found in that study strongly suggests that infants were generalizing based on features, not overlapping consonants between input and test. Nevertheless, future research might explore the effects of overlapping variability between input and test.

Returning to the view that infants in Exp. 2 implicitly entertained conflicting hypotheses about feature- and non-feature-based generalization, it is interesting to note that infants might have failed to generalize for two reasons. One is that the conflicting input did not let either generalization "win" (examples supporting each generalization were equally frequent). The other is that, if the true regularity were feature-based, it is a suspicious coincidence that all four words contain *p* and *t*. Therefore, the more likely, "winning" generalization is the one involving particular consonants (e.g., Tenenbaum & Griffiths, 2001). There is growing evidence that when infants encounter input in a subset-superset relation like the one used here (e.g., *p*/*t* is a subset of all voiceless consonants), they appear to make the generalization that avoids suspicious coincidence (e.g., Gerken, 2006, 2010; Xu & Tenenbaum, 2007). These studies suggest that, if we had included test items that were consistent with the consonant-based generalization, infants would have discriminated *p*/*t* from *p*/*b* test items. A parallel experiment by Gerken (2006) suggests that infants would indeed make the narrower generalization.

4. General discussion

The two experiments reported here reveal three new observations about infant language learning. First, the robust generalization seen in both Partially Conflicting and Non-Conflicting Conditions of Exp. 1 clearly show that infants are able to make a phonological generalization from only four input words that span just 4.5 s. This learning is an order of magnitude more rapid than that seen in previous studies. Such rapid learning raises the question of why real language learning takes as long as it does. Of course language learning entails making and coordinating many structural generalizations, and certainly this process takes time. In addition, however, it is also possible that a particular structural generalization might be learned very rapidly and then either relearned or strengthened and integrated into the linguistic system over time. Thus the learning problem might be only a small part of what we need to understand about the process of language development. Infants' rapid learning also prompts a methodological issue. If infants can learn from only four input examples, and the particular examples matter for generalization, we need to acknowledge the possibility that infants in our studies with many more input examples might generalize or fail to generalize based on a particular sample of the input that each infant has encoded from the larger input set. Indeed, an unpublished study from our lab suggests that simply re-ordering the stimulus items in a 24-word input set to eliminate local sets of items that support multiple generalizations changes a null result into a strong novelty preference (Gerken, Knight, & Quam, submitted for publication). Therefore, we as researchers need to consider the possibility that 2 min of exposure may be too long, in that we lose control over the particular input that individual infants are encoding.

Second, the current experiments extend previous studies: Infants' listening behavior at test is sensitive to the strength of evidence for a particular generalization. When the entire input set supports only one linguistically relevant generalization, infants showed a novelty preference, suggesting that their representation of that generalization is very robust. When the entire input set supports one generalization, but pairs of input items also support a second generalization, infants make the generalization supported by the entire input set. Nevertheless, their familiarity preference suggests that they were affected by the possibility of another generalization. And when the entire input set supports two competing generalizations, infants fail to generalize.

Third, consistent with previous studies, infants appear to notice non-feature-based generalizations (Cristià et al., 2011; Gerken & Bollt, 2008; Seidl & Buckley, 2005). The new information added by Exp, 2 is that, when feature-based and non-feature-based generalizations are put into conflict, infants do not appear to be biased to make the former. Thus, although infants may be biased toward *detecting* similarities across input items that are feature-based (Mesgarani et al., 2014; Saffran & Thiessen, 2003), they do not appear to be biased toward *generalizing* based on features if they also detect a competing basis of generalization. Clearly, more work must be done to understand the role of putative linguistic biases in language development.

In sum, infants are able to learn from many fewer input examples than previously shown, but their rapid learning does not appear to reflect a bias toward feature-based generalization.

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