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Learning builds on learning: Infants' use of native language sound patterns to learn words

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Abstract

The present research investigated how infants apply prior knowledge of environmental regularities to support new learning. The experiments tested whether infants could exploit experience with native language (English) phonotactic patterns to facilitate associating sounds with meanings during word learning. Fourteen-month-olds heard fluent speech that contained cues for detecting target words; they were embedded in sequences that occur across word boundaries. A separate group heard the target words embedded without word boundary cues. Infants then participated in an object label-learning task. With the opportunity to use native language patterns to segment the target words, infants subsequently learned the labels. Without this experience, infants failed. Novice word learners can take advantage of early learning about sounds scaffold lexical development.

Keywords

word learning; statistical learning; phonological development; infancy

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A fundamental process in language acquisition is to map the sounds of words to their meanings. This requires forming a sound representation, a meaning representation, and linking the two. Acquiring new words is a formidable task for novice language learners. Initially, vocabulary acquisition proceeds slowly and effortfully. By age 2, infants typically become skilled and efficient word learners (Bloom, 2000; Fenson et al., 2007; McMurray, 2007). Essential to this developmental progression is the way that learning builds on prior learning. Infants must detect the environmental cues that are available to support word learning, and must learn how to effectively exploit these cues.

Infants' experiences shape how they learn, a process that is illustrated by the acquisition of the shape bias in word learning. One key task in word learning is to determine the range of items that a new word refers to. Smith and colleagues have proposed that infants use consistent patterns in their environments to solve this problem (e.g., Samuelson & Smith, 1999; Smith, 2000; Smith, Colunga, & Yoshida, 2010). One such pattern is that the object categories and names that infants encounter tend to be organized around shape (Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002); for example, within the categories of balls and cups, items not only share a label, they also have similar shapes. When infants learn the shared name for items within a category, they have the opportunity to detect this name-shape relation. Moreover, when infants perform the larger scale generalization that "——'s are ——- shaped" (Smith et al., 2002, p. 14), they can infer how new object names map onto entire groups of items with the same shape. Importantly, the experience of learning the names for many shape-based categories induces the shape bias; the shape bias, in turn, produces more efficient vocabulary acquisition (Smith et al., 2002). In fact, the shape bias can be induced in the laboratory by enriching infants' experience with shape-based categories. Following this enrichment, infants experience accelerated vocabulary growth (Smith et al., 2002). Learning about environmental patterns creates changes in how infants approach new learning problems.

The shape bias demonstrates how infants can detect a cue to structure in their environments, then apply the cue to promote further learning—how learning begets learning. In this case, the information helps infants focus on the appropriate meanings for new words. Here, we ask whether the same general mechanism operates when infants learn about the sound sequences that form potentially meaningful units in the ambient language. How do infants identify the sound sequences in fluent speech that correspond to individual words that can be associated with meanings? A substantial literature has established that infants learn a remarkable amount about native language sound structure even before they start to produce their first words (reviewed in Saffran, Werker, & Werner, 2006). The next crucial step is to determine how infants apply this learning about linguistic sounds to learn new words.

A significant challenge in forming sound representations is to segment individual words from fluent speech. Before a listener has a substantial vocabulary, it is difficult to identify where each word starts and stops because the speech signal lacks reliable acoustic word boundary markers (Brent, 1999). However, the ability to segment fluent speech is essential for word learning because one can only associate a word with its meaning if the word has been identified. The linguistic environment provides infants with patterns that they can use to solve this problem (see reviews in Brent, 1999; Jusczyk, 1999). One source of information for segmenting words comes from phonotactic patterns, which include the frequency with which phonemes and phoneme combinations occur in a given language, as well as the frequency with which they occur at particular word positions. Phonotactic information marks word boundaries because in a given language, some phonemes do not occur at certain word positions, or do not occur within words in certain combinations. For example, English words do not begin or end with the consonant cluster /vt/. When a listener encounters this sequence, knowledge of English phonotactics should suggest how to parse the utterance; thus, the phrase "give to" is heard as /gIv tu/, not /gIvt u/ or /gI vtu/. Accordingly, adults identify words in fluent speech more rapidly when phonotactic word boundary cues are present than when they are absent (McQueen, 1998).

Thus, infants' linguistic input provides cues to cohesive word units, just as it provides cues to shape-based category structures. In both cases, learners must detect the regularities in the input in order to take advantage of them to promote further learning. During early language acquisition, there is evidence of sensitivity to phonotactics. Mattys and Jusczyk (2001) reported that infants can use phonotactics to detect words. In the experiment, 9-month-olds listened to target words embedded in sentences with good phonotactic cues to word boundaries. That is, at word onset and word offset, the target words were embedded in phoneme combinations that do not tend to occur within English words, but do occur across word boundaries. During testing, infants listened longer to repetitions of the target words than to novel words, suggesting that they recognized the target words when presented in isolation. When infants heard target words embedded in sentences without phonotactic segmentation cues, they did not seem to recognize the words, but rather treated them like entirely novel words (i.e., they showed no listening preference). While listening preferences do not demonstrate that infants have extracted cohesive word-like units per se, this pattern of results does suggest that the infants detected the target words in the supportive phonotactic context, but not when the phonotactic information was unavailable.

The ability to detect words in fluent speech, using phonotactics or other cues, is a crucial skill for language acquisition. In support of this notion, Newman, Ratner, Jusczyk, Jusczyk, and Dow (2006) found that infants' early word segmentation abilities are associated with later language development. Infants (7.5- to 12-month-olds) initially participated in word segmentation tasks that incorporated a variety of segmentation cues, such as prosody and phonotactics. At 2 years of age, toddlers who showed successful segmentation as infants had larger vocabularies than those who had not segmented as infants. Infant word segmentation performance was also related to vocabulary and syntax at 4 to 6 years of age. These findings suggest that word segmentation ability lays a foundation for subsequent language development (see also Singh, Reznick, & Xuehua, 2012). Children who have difficulty identifying words in fluent speech may find it challenging to associate meanings with new words and to learn how words function in sentences.

The preceding discussion indicates that phonotactic information is a valuable environmental cue for finding words, infants can detect this cue, and that early segmentation ability is a fundamental skill for language acquisition. However, the extant literature does not reveal precisely how infants use phonotactic information. That is, does phonotactic information help infants associate sounds with meaning to acquire new words? Previous experiments have shown that lab-based experience with artificial language materials can promote word learning (Graf Estes, Evans, Alibali, & Saffran, 2007; Lany & Saffran, 2010, 2011), but we do not yet know how experience with naturally-occurring phonotactic patterns affects the process of associating sounds with meanings. As with the shape bias, sensitivity to this environmental regularity may facilitate word learning. The phonotactic patterns that occur within versus across word boundaries can be used to segment individual words from continuous speech, then form sound sequence representations that are readily available to be mapped to meanings.

The goal of the present experiments was to investigate how infants integrate prior experience with naturally-occurring environmental regularities to support subsequent learning. Specifically, we examined how novice word learners apply knowledge of native language sound patterns to support the process of associating sounds with meanings. To address this issue, Experiment 1 first established a set of object labels that 14-month-olds did not readily learn in the absence of supporting information about the sounds of the labels. Experiment 2 examined whether infants would learn those object labels when they first had the opportunity to use phonotactic word boundary cues to segment the target words.

Experiment 1

The purpose of Experiment 1 was to determine a pair of object labels that 14-month-olds do not readily learn in order to use this pattern as a baseline for Experiment 2. A version of the Switch task (Werker, Cohen, Lloyd, Casasola, & Stager, 1998) was used to measure object label learning in both experiments. In the Switch task, infants first habituate to two label-object pairings. They then view test trials in which the original pairings are switched, as well as trials in which the original pairings are maintained. If infants learned the associations between the labels and objects, they should look longer during the switched trials.

In establishing the Switch task as a measure of object label learning, Werker and colleagues (1998) reported that 14-month-olds can associate phonetically distinct labels with a pair of objects. Importantly, although this finding has been replicated (Byers-Heinlein, Fennell, & Werker, 2013), there is also substantial evidence that object label learning in novice word learners (i.e., infants under 18 months of age) is fragile. For example, Chan et al. (2011) found that 14-month-olds failed to learn labels in the Switch task when the objects were presented by a (video-recorded) woman performing actions with them. Even older infants, 17-month-olds, can fail to associate words with objects in the absence of some kind of supporting information, like an infant-directed speaking style (Graf Estes & Hurley, 2013). The evidence is even more mixed in younger infants. Werker et al. (1998) found that 12-month-olds failed to learn object labels in the Switch task, but MacKenzie and colleagues (MacKenzie, Curtin, & Graham, 2012; MacKenzie, Graham, & Curtin, 2011) have reported successful learning of other labels at this age. A series of experiments from Hollich and colleagues (2000; Experiments 4-9) suggested that 12-month-olds require multiple social-referential cues during labeling to learn new object names, cues that are absent in the Switch task. Thus, the literature on early word learning suggests that while infants do learn effectively in many circumstances, the ability is fragile, particularly at young ages.

The current experiments used a variation of the Switch task that has been found in previous studies to be difficult for infants. With the general parameters used here, even 17-month-olds failed to learn label-object associations unless they heard the labels in infant-directed prosody (Graf Estes & Hurley, 2013) or they previously had artificial language segmentation experience (Graf Estes et al., 2007). Across experiments, the labels were *gaffe* and *tove*, taken from the phonotactic segmentation task that Mattys and Jusczyk (2001) designed. We anticipated that under these conditions, infants would fail to respond to the label-object associations. It is a little unconventional to begin by predicting that infants will fail to learn. However, because the ultimate goal was to show the facilitative effect of phonotactic information, it is important to provide this failure as a baseline. In addition, one of our overarching assumptions is that forming such associations early in lexical development is hard, and therefore it is important to have demonstrations of both success and failure.

Method

Participants—Eighteen infants (10 female) participated in Experiment 1 (*M* age = 14.3 months, range 13.7-15.3 months). The infants were born full term and had no history of hearing impairments or chronic ear infections. All infants came from English-speaking homes. Additional infants were excluded from analyses due to fussiness (i.e., crying, repeatedly trying to leave parent's lap; *n* = 13[1]), excessive movement (*n* = 1), and being distracted by an object in the test booth (*n* = 3). Before conducting the significance tests reported below, one additional infant was identified as an outlier (mean looking time difference score over 2 *SD* from the mean) and was excluded from analyses.

Stimuli—A female native English speakfer recorded tokens of the target words *gaffe* /gæf/ and *tove* /tov/ to be used as object labels. She produced them in isolation with infant-directed prosody. There were four tokens of each label, separated by 750 msec of silence and repeated in a loop. The program Praat (Boersma & Weenink, 2010) was used to measure the amplitude, fundamental frequency (F0, a measure of pitch), and duration of the labels. The values are reported in Table 1.

As shown in Figure 1, two novel objects were paired with the labels. The items were images of three-dimensional objects that differed in shape and color. Object 1 was displayed at 5.1 × 6.4″ and object 2 was displayed at 6.6 × 5.9″. Each object bounced in an arc within a white rectangle (40.4 × 24.5″) at the center of the screen. The surrounding area of the 42″ (diagonal) television screen was dark.

Procedure—The infant sat on a parent's lap approximately 3 feet from a large screen television with integrated speakers. To prevent bias, the parent listened to music over headphones and the experimenter controlled the experiment from a separate booth, blind to the identity of the stimuli being presented. The program Habit X (Cohen, Atkinson, & Chaput, 2004) was used to control stimuli presentation and record looking time in a version of the Switch task. Although the Switch task does not measure the full range of referential understanding that word knowledge entails, it taps a key process in word learning, associating word form representations with meaning representations.

The infant first viewed a familiarization trial, intended to provide experience with the audio-visual stimulus presentation before the first habituation trial. A computerized image of a small rotating grey screen appeared on the television while repetitions of the nonword *neem* played.

[1]There was a high drop-out rate due to fussiness in Experiments 1 and 2. This could bias the results toward infants with relatively long attention spans. Our conclusions may be based on a sample that is not typical of all 14-month-olds. However, the drop-out rate in the present experiments is similar to the rates in prior experiments using versions of the Switch task with 14-month-olds (Fennell, Byers-Heinlein, & Werker, 2007; Fennell & Waxman, 2010; Werker, Fennell, Corcoran, & Stager, 2002). Thus, the present sample of infants may be comparable to the samples in prior experiments—including many experiments that have influenced understanding of early label learning.

Following the familiarization trial, the habituation trials began. At the start of each trial, a cartoon played to capture the infant's attention. When the infant looked at the screen, one of the label-object pairings played; it continued until the infant looked away from the screen for at least 1 second or after a maximum of 20 seconds. The two label-object pairings were presented one at a time, randomized by blocks, until the infant habituated. The habituation criterion was met when the infant's average looking time across three trials decreased to 50% of his or her average looking time across the first three trials.

The test trials started immediately after the infant habituated or viewed a maximum of 25 habituation trials. There were two types of test trials. During Same trials, the infant viewed the original label-object pairings. During Switch trials, the original label-object pairings were switched (e.g., object 1 was paired with label 2). If infants learned the original label-object associations, they should look longer during the switch test trials when those associations were violated. The dependent variable was the looking time difference score, calculated as mean looking duration during switch trials minus same trials. A positive value indicates greater attention to the switch test trials.

There were two blocks of four test trials; each block contained two same trials and two switch trials. Infants were randomly assigned to participate in one of eight pseudo-randomized test orders that counterbalanced the presentation of same and switch trials. Preliminary tests indicated no effects of test order or sex, therefore analyses collapsed across these variables.

Results and Discussion

Infants habituated in an average of 11.67 trials (SD = 5.9) and 108.1 seconds (SD = 66). Two infants failed to meet the habituation criterion and viewed the maximum 25 habituation trials; the results are the same with these infants excluded. Figure 2 shows infants' mean looking time difference score and Table 2 reports mean looking times to same and switch test trials. A paired samples t-test revealed no difference between infants' looking time difference scores in blocks 1 versus 2, $t(17) = 1.17$, $p = .258$, $d = .42$, therefore subsequent analyses collapsed across blocks. To examine learning performance, a one-sample t-test compared infants' looking time difference scores to zero, representing no difference in attention to same versus switch trials. It revealed that the scores did not differ significantly from zero, $t(17) = 1.33$, $p = .200$, $d = .31$. (In Figure 2, data are shown separated by block for consistency with Experiment 2. We also confirmed that infants showed non-significant difference scores in blocks 1 and 2 ps > .16.) There was no evidence that infants noticed the switch test trials. Ten infants displayed positive difference scores (longer looking to switch trials) and 8 infants displayed negative difference scores.

Because infants controlled the duration of their label exposure during habituation, we examined whether label learning performance correlated with attention during habituation. There were no significant correlations between looking time difference scores and trials to reach habituation, $r = .193$, $p = .444$, or time to reach habituation, $r = -.162$, $p = .552$. (For consistency with Experiment 2, we also examined the correlations specifically for test block 1. As in the overall analysis, there were no reliable correlation between difference scores and trials to reach habituation, $r = .184$, $p = .463$, or time to reach habituation, $r = .224$, $p = .373$.) Attention during habituation was not related to label learning performance.

In Experiment 1, 14-month-olds exhibited no evidence of learning the label-object pairings for *gaffe* and *tove*. From one perspective, this is not entirely surprising. The design of Experiment 1 was based on a task in which older infants have failed to learn labels without some form of supplemental support (Graf Estes et al., 2007; Graf Estes & Hurley, 2013; Hay, Pelucchi, Graf Estes, & Saffran, 2011). There is evidence from other variations of the Switch task that 14-month-olds (Byers-Heinlein et al., 2013; Werker et al., 1998), and even younger infants (12-month-olds; MacKenzie et al., 2012; MacKenzie et al., 2011) can learn phonetically distinct object labels, but the task has revealed vulnerabilities in learning as well. For example, Werker et al. (1998) reported that 14-month-olds only displayed learning when objects moved during labeling, not when they were stationary. Chan and colleagues (2011) also found that 14-month-olds did not learn labels when the objects were being moved by a person.

Because word learning is an emerging process in the first months of the second year, many factors could push infants toward success or failure (Smith & Thelen, 2003; Thelen & Smith, 2006). For example, the Switch task in the current experiment differed from Werker and colleagues' (1998) original test in several ways. The labels in Experiment 1 have fewer lexical neighbors (i.e., words that differ from a given word by a single phoneme) than the labels that Werker et al. used, *lif* and *neem*. *Gaffe* has seven neighbors (calf, half, laugh, goof, gag, gang, gas) and *tove* has six (dove, toad, toll, toe, tore, stove), whereas *lif has* 15 neighbors (leaf, if, laugh, life, loaf, lick, lid, limb, lip, lit, live, lin, if, cliff, lift) and *neem* has nine (beam, seem, team, name, kneel, neat, need, niece, knee) (calculations based on Storkel & Hoover, 2010). Thus, *gaffe* and *tove* may be less like infants' experience with the sound patterns of other native language words, making them harder to acquire (Graf Estes & Bowen, 2013). In addition, the objects in Experiment 1 were two simple novel objects, each with a single color; the objects that Werker and colleagues used had greater variation in color, were more distinctive, and came from familiar categories (a dog and a truck). The novelty or discriminability of the objects could make the labels in the present experiment more difficult to learn.

While it is beyond the scope of the present investigation to precisely identify all the design features that affect infants' performance in the Switch task, the variation in performance observed across studies illustrates the malleability of early word learning. Many kinds of manipulations can promote or prevent successful learning. What is key here is that Experiment 1 established a learning task that is difficult for 14-month-olds to master. This design can now be used to investigate how phonotactic information does (or does not) facilitate learning.

Experiment 2

Experiment 2 tested whether infants can exploit their prior experience detecting sound structure in the ambient language to facilitate word learning. The design of the task was based on work by Graf Estes et al. (2007) that showed that 17-month-olds connected statistical learning experience in an artificial language with object label learning (see also Lany & Saffran, 2010, 2011). In the current experiment, 14-month-olds first listened to (English) fluent speech passages based on the phonotactic word segmentation task conducted by Mattys and Jusczyk (2001). One group of infants listened to passages that contained good phonotactic cues to word boundaries for two target words; the target words were embedded in phoneme combinations that occur across word boundaries but not within words (the Good Cues condition). A second group of infants heard passages that contained poor phonotactic word boundary cues for the same target words; the words were embedded in phoneme combinations that tend to occur within words rather than across word boundaries (the Poor Cues condition). A key aspect of the design is that the phonotactic patterns were based on native-language phonological regularities, not lab-based training. Infants must rely on their accumulated experience with phonotactics to take advantage of the cues. All infants then participated in the same label learning task in which the target words (*gaffe* and *tove*, identical to Experiment 1) acted as labels for novel objects. Importantly, in both conditions the target words occurred with equal frequency before they acted as object labels. The difference was whether or not infants first heard good phonotactic cues for detecting the words before attempting to associate them with objects.

The hypothesis was that infants would use prior knowledge to support new learning. We predicted that infants would use knowledge of native language sound patterns to detect the new words in fluent speech, and subsequently use this information to support the process of mapping the words to objects. Specifically, we expected infants to show facilitation of learning only when they heard novel words embedded in passages that contained good phonotactic word segmentation cues. Phonotactic segmentation experience should promote the formation of strong phonological representations of individual words that are readily available for mapping to meanings. In contrast, we predicted that when the novel words were embedded in passages that contained poor phonotactic cues to word boundaries, it would be challenging for infants to detect the words and build representations of them. Robust word form representations would be unavailable; therefore we expected infants to display difficulty learning, just as they did in Experiment 1 when they had no prior label exposure. In both the Good Cues and Poor Cues conditions, the passages provided the same amount of exposure to the words as well as some referential context because infants heard the labels across several sentences. However, only the Good Cues condition allowed infants to use language-specific patterns to scaffold the mapping process.

Method

Participants—Thirty-eight 14-month-old infants (19 females) were randomly assigned to participate in the Good Cues condition (*M* age 14.4 months, range: 13.8-15.3 months; 9 females and 10 males) and Poor Cues condition (*M* age 14.4 months, range: 13.7-15.1 months; 10 females and 9 males).Infants met the same inclusion criteria as in Experiment 1. All infants came from English-speaking homes. Seven infants also heard a second language for approximately 16 hours per week or less, based on parental report (Good Cues condition $M = 5.9$ hours; Poor Cues condition $M = 5.0$ hours). The pattern of results is unchanged when these infants are excluded. Before performing the significance tests, one additional infant in the Good Cues condition was identified as an outlier (listening time difference

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score more than 2 *SD* from the mean) and was excluded from the analyses. An additional 22 infants were excluded due to fussiness.

Stimuli

Phonotactic Segmentation Stimuli: Infants listened to passages that contained the target words *gaffe* and *tove*. The words were embedded in the sentences that Mattys and Jusczyk designed to test 9-month-olds' use of phonotactics to detect words (see Table 3). Mattys and Jusczyk (2001) selected the phonotactic contexts based on an analysis of the Bernstein (1982) corpus of child-directed speech performed by Mattys, Jusczyk, Luce, and Morgan (1999). They identified consonant-consonant (CC) combinations that were similar in overall frequency in English, but differed in the likelihood that they occurred within words versus across word boundaries. The target words, *gaffe* and *tove,* were chosen to fit with the CC combinations to produce phoneme sequences with good or poor phonotactic cues for segmentation. In the Good Cues condition, the sequences were X *n-gaffe-h* X (/*n* gæf h/) and X *v-tove-t* X (/v tov t/); the X indicates syllables that end or begin with a given phoneme, such as in the utterances "bean *gaffe* hold" and "live *tove* takes." The sequences /ng/, /fh/, and /vt/ have low probability of occurring within words and high probability of occurring between words, which should facilitate the segmentation of the target words embedded in these sequences. In the Poor Cues condition, the sequences were X *ng-gaffe-t* X (/ŋ gæf t/) and X *f-tove-n* X (/f tov n/), as in the utterances "king *gaffe* tool" and "calf *tove* needs". The sequences /ng/, /ft/, and /vn/ have low probability of occurring across word boundaries and higher probability of occurring within words in English. These patterns do not provide support for segmentation and could hinder individuation of the target words from the speech stream.

Based on these patterns, Mattys and Jusczyk (2001) created six-sentence passages for each target word in each condition. In the present experiment, infants listened to both target words in either the Good Cues or Poor Cues condition. They listened to the sentences in blocks: six *gaffe* sentences, followed by six *tove* sentences, and these blocks were repeated. Infants were randomly assigned to start with the *gaffe* or *tove* passage.

The speaker from Experiment 1 recorded the sentences in an infant-directed speaking style. She was naïve to the conditions of the phonotactics manipulation and her script included foil sentences to mask the manipulation. To confirm that the target words and surrounding phonotactic contexts were pronounced accurately, six adult native English speakers listened to the passages. For each sentence, they transcribed the target word, the word preceding the target, and the word following the target. Scoring was based on the consonants in the target words and the consonants immediately surrounding the target words (i.e., the CC combinations that produced good or poor phonotactic word boundary cues). The mean percent of consonants identified correctly was 98% in the Poor Cues condition and 97% in the Good Cues condition. These findings confirm that listeners largely heard the target words and phonotactic contexts as they were written.

We also performed acoustic analyses to examine whether the target words were more acoustically prominent in the Good Cues or Poor Cues condition. Table 2 shows the mean amplitude, pitch, and duration for the target words and the immediately preceding and following words. Comparisons between the target words and the surrounding words did not reveal any consistent patterns; the target words were not consistently louder, higher pitched, or longer. The acoustic characteristics of the target words also did not differ across the phonotactic cue conditions. In addition, there was no difference in the duration of the very brief silences that sometimes occurred before and after the target words in the Good Cues passages (*M* = 11 msec, *SD* = 9) and Poor Cues passages (*M* = 14 msec, *SD* = 12). Overall, the acoustic analyses did not reveal any supplemental word boundary cues.

The amplitude of the sentences was equalized using Adobe Audition. They were played at approximately 65-70 dB, as measured by a sound level meter at the infants' location. The total duration of the segmentation phase was 1 minute 40 seconds in both conditions.

Object labeling stimuli: The labels and objects from Experiment 1 were used in Experiment 2.

Procedure—In Experiment 2, infants first listened to passages of fluent speech that contained the target words while watching a soundless animated cartoon, seated on a parent's lap. Infants were randomly assigned to listen to passages in the Good Cues or Poor Cues condition. After listening to the speech stream, the infants participated in the Switch task described in Experiment 1. All infants viewed the same label-object pairs. The key difference was whether they first heard the words in a context that presented good or poor phonotactic segmentation cues before the words served as object labels.

Preliminary tests indicated that there were no effects of sex or test order across the 8 counterbalanced orders, therefore analyses collapsed across these variables.

Results and Discussion

Infants in the Good Cues condition viewed a mean of 10.32 trials during habituation (*SD* = 5.3), with a total time to habituate of 130.1 seconds (*SD* = 100). Infants in the Poor Cues condition viewed 9.95 trials (*SD* = 4.5), with a total time to habituate of 93.9 sec (*SD* = 33). There were no significant differences in number of trials to reach habituation, $t(36) = .23$, $p = .820$, $d = .08$, or time to reach habituation, $t(36) = 1.49$, $p = .145$, $d = .54$. *One* infant in each condition failed to habituate. The pattern of results is unchanged with these infants excluded.

To analyze infants' learning performance, a 2 (Test block: 1 versus 2; within subjects) × 2 (Phonotactics condition: Good Cues vs. Poor Cues; between subjects) mixed design ANOVA was conducted on infants' looking time difference scores. Mean looking time difference scores are shown in Figure 2 and the same and switch trial mean looking times appear in Table 2. There was no main effect of Test block or Phonotactic condition, $Fs < 1$. However, there was a significant interaction of block × phonotactic condition, $F(1, 36) = 4.28$, $p = .046$, $\eta_p^2 = .106$. To probe the interaction, independent samples t-tests revealed that infants in the Good Cues condition had significantly larger looking time difference scores than infants in the Poor Cues condition during block 1, $t(36) = 231$, $p = .027$, $d = .76$. The difference was not significant in block 2, $t(36) = -1.07$, $p = .294$, $d = .34$. This analysis indicates that during the first test block, infants in the Good Cues condition showed greater differentiation of the same and switch test trials than infants in the Poor Cues condition.

To examine whether infants in each condition successfully learned the label-object pairs, we tested whether infants looked reliably longer to switch trials than same trials. If so, looking time difference scores should be greater than zero. In the Good Cues condition, infants' scores were significantly greater than zero during block 1, single samples $t(18) = 3.50$, $p = .003$, $d = .80$. Fifteen of 19 infants displayed positive difference scores (longer looking to switch trials). In block 2, the difference from zero was not significant, $t(18) = -.635$, $p = .534$, $d = .15$. Seven infants of 19 displayed positive difference scores. In the Poor Cues condition, looking time difference scores did not differ from zero during block 1, $t(18) = -.343$, $p = .735$, $d = .08$, or block 2, $t(18) = .858$, $p = .402$, $d = .20$. During block 1, 10 of 19 infants displayed positive difference scores and during block 2, 12 infants displayed positive difference scores. In sum, during the first block of test trials, when attention was most tightly linked to experience during habituation, infants in the Good Cues condition displayed successful label learning via longer looking during test trials in which the original label-object pairings were violated. Infants in the Poor Cues condition did not show evidence of label learning.

In the Good Cues condition, the learning pattern revealed in the first test block did not persist in the second block. The change in response is not unprecedented or unanticipated. Although previous experiments have shown that greater attention to switch test trials does not change significantly over test blocks (Graf Estes et al., 2007; Graf Estes & Hurley, 2012), other studies have reported changes in infants' sensitivity over the course of testing when the dependent measure relies on attentional differences (Gerken, Wilson, & Lewis, 2005; Sahni, Seidenberg, & Saffran, 2010). With repeated exposure to novel test items, the novelty may decrease. As infants accumulate knowledge about the switch trials, they may no longer show strong differentiation between same and switch trials. The connection to the habituation trials decreases and all trials become increasingly familiar. Thus, the first block of test trials may be the most sensitive to infants' label learning skills. This is likely why infants in the Good Cues condition displayed successful learning only during block 1, as shown in Figure 2.

Because infants controlled the duration of label exposure during habituation, a set of correlations tested whether label learning performance and attention during habituation were related. The analyses focused on looking time difference scores during block 1, the block during which the strongest evidence of learning occurred. In the Poor Cues condition, the correlations between looking time difference scores and number of trials to reach habituation ($r = .297$, $p = .216$) and time to reach habituation ($r = .310$, $p = .197$) were not significant. In the Good Cues condition, there were also no significant correlations for trials to reach habituation ($r = .015$, $p = .951$) or time to reach habituation ($r = .063$, $p = .798$). (For consistency with Experiment 1, we also examined the correlations with looking time difference scores collapsed across test blocks. In the Good Cues condition, there were no significant correlations between overall looking time difference scores and trials ($r = -.332$, $p = .165$) or time to reach habituation ($r = -.346$, $p = .146$). In the Poor Cues condition, there were also no significant correlations for trials ($r = .207$, $p = .394$) or time to reach

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habituation ($r = -.016$, $p = .949$)). Thus, it does not seem that increased attention during habituation can explain why infants demonstrated learning of the labels in the Good Cues condition, but not in the Poor Cues condition or in Experiment 1 when infants had no prior exposure to the labels.

Previous experiments have also shown that despite similar habituation times, infants can display different learning patterns (Graf Estes et al., 2007; MacKenzie et al., 2012; Thiessen, 2007). During habituation, infants encode enough information about the label-object pairings for attention to decline. However, this encoding may be insufficient to detect when a familiar object and a familiar label occur in novel pairings during switch trials. Here, infants in all conditions declined in attention during habituation, but only infants in the Good Cues condition learned enough to reliably detect the switched label-object pairings.

A final key consideration is that the phonotactic context in the Poor Cues condition could have actively inhibited infants' learning. In these passages, the consonant clusters at the target word onsets and offsets occurred more frequently within English words than across words. This could have obscured the location of the word boundaries, making it difficult to determine the correct phonological sequences (e.g., in the phrase “fang gaffe tine,” *gaffe* could be heard as /fængæft/). If this is the case, learning labels with poor phonotactic cues should be even more challenging than learning them with no prior segmentation experience at all. The analyses reported to this point suggest that this is not the case. In both the Poor Cues condition and in Experiment 1, infants displayed no evidence that they learned the labels. We also performed a set of independent samples t-tests across Experiment 1 (no segmentation cues) and the Poor Cues and Good Cues conditions of Experiment 2. The t-tests showed that the looking time difference scores of infants in Experiment 1 did not differ from those of infants in the Poor Cues condition in test block 1 ($t(35) = .23$, $p = .823$, $d = .07$) or in block 2 ($t(35) = 1.69$, $p = .101$, $d = .56$). Performance in both of these conditions differed significantly from the performance of infants in the Good Cues condition during block 1 (Experiment 1 vs. Good Cues, $t(35) = 2.31$, $p = .027$, $d = .76$; Good Cues vs. Poor Cues comparison is presented above).

Thus, there is no evidence that hearing words embedded with poor segmentation cues inhibited label learning. Rather, the presence of good phonotactic cues facilitated learning. The findings of Experiment 2 are particularly remarkable because the infants in the Good Cues and Poor Cues conditions had the same exact amount of exposure to the words before they served as object labels. In the presence of language-specific word segmentation cues, infants spontaneously treated the words differently than when they lacked this information. With the phonotactic cues, the infants detected potential meaningful units and associated them with objects.

General Discussion

The results of the present experiments indicate that infants can use learning about native language sound patterns to feed word learning. Experiment 1 established a set of labels and objects that 14-month-olds find difficult to associate when the learning environment lacks supplemental support. Experiment 2 used the same labels and objects, but provided additional cues for building phonological representations of the labels. When infants heard target words embedded in sentences that contained good phonotactic word boundary cues, they successfully learned the target words as object labels. When infants heard the same target words embedded with poor phonotactic segmentation cues, infants did not display any evidence of learning the labels. Simple exposure to the words in fluent speech passages was not sufficient to promote label learning. Across cue conditions, infants heard the target words the same number of times. However, infants required the presence of language-specific word boundary cues to use the experience listening to the word forms to facilitate object label learning. The findings suggest that these novice word learners took advantage of their native language knowledge to find the words, which then allowed them to associate the words with meanings. The process observed here illustrates how infants build learning from prior learning. Infants detect regularities in their environments, then use this information to support subsequent acquisition of higher level structure.

To establish a baseline for the effects of prior knowledge of native language sounds, Experiment 1 demonstrated conditions under which 14-month-olds failed to learn a pair of novel object labels. The pattern of performance seems to conflict with prior studies that have shown successful learning in 12- to 14-month-olds (MacKenzie et al., 2012; MacKenzie et al., 2011; Werker et al., 1998). However, the finding also highlights that for novice word learners, the process of associating sounds with meanings is not highly stable or robust. Across experiments, variations in objects, words, labeling contexts, testing contexts, referential information, and social information can drive performance toward success or failure (Fennell & Waxman, 2010; Rost & McMurray, 2009, 2010; Thiessen, 2007; Yoshida, Fennell, Swingley, & Werker, 2009). This variability in performance across experiments is informative about the state of the emerging system (Smith & Thelen, 2003; Thelen & Smith, 2006). When learners are developing a new behavior, it is not yet entrenched, so performance can be perturbed. The ability to disrupt or facilitate learning allows for a window on development; it allows us to probe the kinds of information that infants access when they attempt to learn in a task that is challenging.

We investigated how infants use patterns from their linguistic environments to facilitate word learning. In doing so, these experiments link two literatures: studies of word learning that have focused on the acquisition of word meanings, and studies of infant speech perception that have focused on early learning about sounds.

The word learning literature points to the influence of many kinds of environmental cues that infants and young children detect, then effectively apply to guide their acquisition of new words. The evidence in this area has focused on the cues learners use to determine what words refer to. One example of this is the shape bias—detecting patterns in the objects and object names in the environment leads to the development of the shape bias, which helps infants extend new object names appropriately (Smith et al., 2002). Similarly, young children can use experience with linguistic contexts to interpret whether a new word refers to an object (“This is a dax”), a characteristic (“This is a dax one”), or an action (“It's daxing”) (Landau, Smith, & Jones, 1992; Yuan, Fisher, & Snedeker, 2012). Experience with the pattern that each object has one (basic level) label seems to be key for developing the principle of mutual exclusivity and using it to map novel names to unnamed objects (Byers-

Heinlein & Werker, 2009; Houston-Price, Caloghiris, & Raviglione, 2010). Although not an exhaustive list, these lines of work illustrate ways that infants build new learning on prior learning about their natural environments in order to determine word meanings.

There have also been demonstrations that infants exploit prior experience to support word learning following brief lab-based experiences with word forms. When infants first have the opportunity to use syllable transitional probability cues to segment words from an artificial language, they can subsequently associate the words with referents (Graf Estes et al., 2007; see also Hay et al., 2011). Without this prior experience, the infants do not learn the associations. Experience with cues to lexical categories in an artificial language also promotes word learning. Lany and Saffran (2010, 2011) presented 22-month-olds with auditory experience with two lexical categories that were marked by a phonological cue (monosyllabic vs. bisyllabic words) combined with a distributional cue (each category co-occurred with different words). Experience with the cues to the lexical categories allowed infants to associate them with distinct semantic categories. Thus, even brief experience with statistical cues to structure in a novel language can support infants' ability to learn new words. The current experiments examined how naturally-occurring experience with a statistical cue supports word learning.

The general mechanism behind the shape bias and these other word learning processes is that infants detect statistical regularities in their daily environments, extract consistent patterns, and then use the information to facilitate further learning. This mechanism is not specific to learning word meanings (or even to language acquisition, for that matter). We propose that the present findings emerge from the same kind of scaffolding effect that originates in infants' detection of statistical regularities in their environments. In this case, infants' ability to discover patterns in the ambient language affects how they learn about the sounds of words. By 9 months of age, infants can detect patterns in the sounds that occur within words versus across word boundaries, as evidenced by their listening preferences (Mattys & Jusczyk, 2001). The current results indicate that at 14 months, infants apply these cues to support the process of associating word forms with their referents. Our findings indicate that infants discover phonotactic word segmentation cues that allow them to extract unfamiliar words from continuous speech and to develop phonological representations of them. Here, the phonological representations were robust enough to allow infants to map them to referents in a task that was otherwise difficult to perform.

Phonotactic patterns may be particularly beneficial to novice word learners, whose ability to link words with referents is fragile. However, for less mature infants, the phonotactic information may be ineffective because the task is beyond their abilities even with phonotactic support. For infants with stronger word learning abilities, phonotactic information may be superfluous; they can readily learn new object names without the segmentation experience. Across development, the weight given to different types of perceptual, referential, and contextual word learning cues changes (Hollich et al., 2000). Similarly, attention to phonotactic cues, and other sound-based information, may change as infants become stronger and more flexible learners.

One direction for future research will be to investigate developmental changes in how listeners take advantage of phonotactic information to learn and process words. Another consideration for future studies is that the present experiments used a limited stimulus set; there was one set of object labels and one set of phonotactic contexts per label in each condition. Follow-up experiments should examine a broader set of labels and phonotactic contexts to establish the generalizability of the effects we observed. An additional limitation of the present study design that should be addressed in further research is that many infants did not tolerate the labeling task. There was a relatively high drop-out rate due to fussiness. While the drop-out rate was similar to the rate in experiments using similar methods (Fennell et al., 2007; Fennell & Waxman, 2010; Werker et al., 2002) the restricted sample may limit how well the present findings apply to the broader population of novice word learners. Using tasks that more infants can complete will allow for stronger, more generalizable conclusions.

By focusing on how experience with the native language sound system affects word learning, the current research contributes to an outstanding issue in the field: Do infants' precocious speech perception skills carry over to higher level linguistic functions, such as building a lexicon (Walley, 1993; Werker & Curtin, 2005)? Previous experiments have suggested that the information infants detect in speech perception tasks (i.e., phoneme distinctions) is not always readily available in word learning tasks (i.e., learning labels that differ by a single phoneme; Stager & Werker, 1997). However, this pattern of results, although reliable and replicable, seems to depend on the nature of the labeling and testing contexts (Fennell, 2012; Fennell & Waxman, 2010; Rost & McMurray, 2009; Werker & Curtin, 2005; Yoshida et al., 2009). Furthermore, other recent experiments have found parallels between infants' perceptual skills and word learning skills. For example, infants can detect differences between phoneme sequences that are consistent versus inconsistent with the native language at around 9 months of age (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994). After age 1, infants also differentiate consistent versus inconsistent sequences in label learning. They successfully learn native language-consistent labels, but not inconsistent labels (Graf Estes & Bowen, 2013; Graf Estes, Edwards, & Saffran, 2011; MacKenzie et al., 2012). The results of Experiment 2 provide further support for the notion that early speech perception skills provide a foundation for word learning. Infants used language-specific cues to detect words that then acted as object labels. They successfully used the output of learning about the native-language sound system as the input for word learning.

In conclusion, the current findings indicate that infants apply learning about their naturally-occurring linguistic environments to facilitate associating sounds with meanings, an essential process in lexical development. Infants can take advantage of prior learning about native language sound patterns to scaffold their emerging word learning skills. More broadly, the present research provides a novel example of a general learning process: infants exploit their early learning to solve new learning challenges.

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Highlights

- Knowledge of sound structure scaffolds word learning for novice learners.
- Infants use native sound patterns to find words and map them to meanings.
- Early learning about the sound system provides a foundation for further learning.

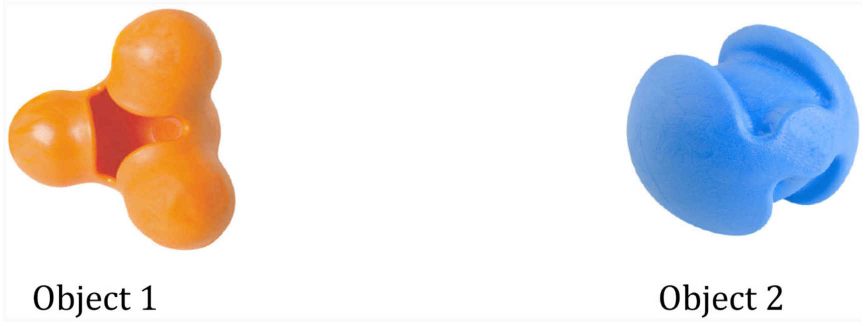

Figure 1.
Novel objects that received labels. Object 1 was labeled *tove* and object 2 was labeled *gaffe*.

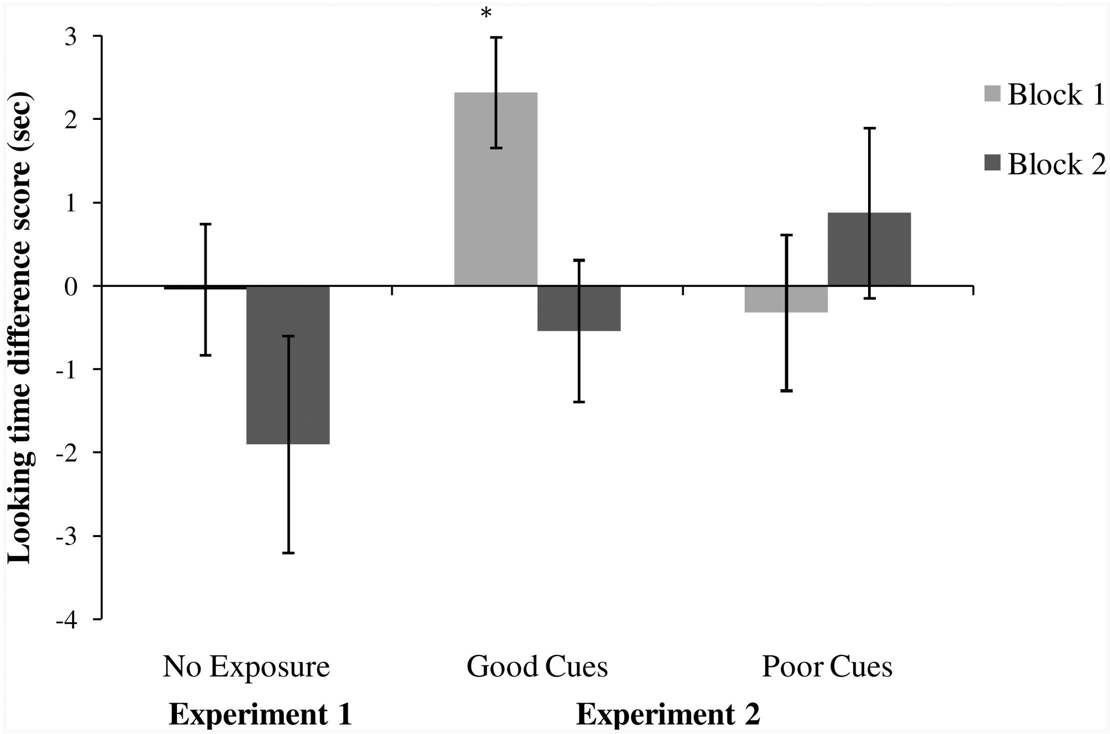

Figure 2.
Infants' mean looking time difference score to switch – same trials in Experiments 1 and 2. Positive values indicate longer looking on switch test trials. Error bars represent standard errors. The asterisk marks the looking time difference score that is significantly different from zero.

Table 1

Acoustic characteristics of the stimuli used in Experiments 1 and 2

	Amplitude in dB *M (SD)*	Pitch (F0) in Hz *M (SD)*	Duration in msec *M (SD)*
Object labels			
Experiments 1 and 2			
Gaffe	78 (65)	302 (22)	757 (70)
Tove	77 (79)	309 (27)	972 (141)
Fluent speech passages			
Experiment 2			
Good Cues condition			
Target word	73 (4.4)	263 (60)[2]	336 (78)
Preceding word	75 (2.5)	292 (53)	404 (91)
Following word	72 (2.9)	218 (37)[2]	447 (184)
Poor Cues condition			
Target word	73 (3.0)[1]	267 (53)	365 (55)
Preceding word	74 (2.9)	311 (44)	387 (63)
Following word	70 (2.5)[1]	237 (39)	386 (76)

Notes. For the Experiment 2 fluent speech stimuli, acoustic analyses are reported for the target words and the words immediately preceding and following the targets. Items marked with 1, 2 differed by $p < .05$.

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Table 2

Infants' mean (and standard deviation) looking time (in sec) to Same and Switch test trials in Experiments 1 and 2

	Block 1		Block 2	
	Same trials	**Switch Trials**	**Same trials**	**Switch trials**
Experiment 1				
No Exposure	7.39 (2.8)	7.35 (3.6)	8.04 (5.3)	6.14 (3.1)
Experiment 2				
Good Cues	6.22 (4.4)	8.54 (5.3)	6.67 (4.6)	6.13 (3.5)
Poor Cues	6.86 (4.0)	6.53 (3.1)	5.52 (3.9)	6.4 (2.7)

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Table 3

Phonotactic segmentation stimuli for the Good Cues and Poor Cues conditions

Good Cues condition
Gaffe
The army is trying a new bean gaffe hold next week.
The old pine gaffe house tends to break too often.
Of course, everyone knows the main gaffe hoist is worn.
A spun gaffe heads the list of new inventions.
Still, some think that a stone gaffe hod is better.
A lean gaffe hall is being used for now.
Tove
A brave tove trusts most forest animals.
Few people know that a live tove takes so much care.
Some think that an eve tove twists old wheat stalks.
The mauve tove tree is hidden in the jungle.
Spies are interested in the dove tove territories.
On sunny days, a groove tove tires very quickly.
Poor Cues condition
Gaffe
The army is trying a new fang gaffe tine next week.
The old tong gaffe tends to break too often.
Of course, everyone knows the king gaffe tool is worn.
A wrung gaffe tops the list of new inventions.
Still, some think that a strong gaffe tin is better.
A hang gaffe tote is being used for the moment.
Tove
A gruff tove knows most forest animals.
Not many people know that a calf tove needs so much care.
Some believe that a skiff tove nibbles old wheat stalks.
The roof tove nest is hidden in the jungle.
Many scientists are interested in buff tove naval stories.
On most sunny days, a leaf tove naps quickly.

Note: Sentences originally designed by Mattys and Jusczyk (2001). Reprinted from Mattys, S. L., & Jusczyk, P. W. (2001). Phonotactic cues for segmentation of fluent speech by infants. *Cognition*, *78*(2), 91-121, with permission from Elsevier.