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Research Article

Phonological Learning Influences Label–Object Mapping in Toddlers

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Purpose: Infants rapidly acquire the sound patterns that characterize their native language. Knowledge of native language phonological cues facilitates learning new words that are consistent with these patterns. However, little is known about how newly acquired phonological knowledge —regularities that children are in the process of learning— affects novel word learning. The current experiment was designed to determine whether exposure to a novel phonological pattern affects subsequent novel word learning.
Method: Two-year-olds (n = 41) were familiarized with a list of novel words that followed a simple phonotactic regularity. Following familiarization, toddlers were taught 4 novel label–object pairs. Two of the labels were consistent with the novel regularity, and 2 of the labels were inconsistent with the regularity.
Results: Toddlers with smaller vocabularies learned all of the novel label–object pairings, whereas toddlers with larger vocabularies only learned novel label–object pairings that were consistent with the novel phonological regularity.
Conclusion: These findings demonstrate that newly learned phonological patterns influence novel word learning and highlight the role of individual differences in toddlers' representations of candidate word forms.

Word learning is a complex process spanning multiple levels of linguistic representations. To successfully learn a word, infants must segment the label from a continuous stream of speech, identify the referent of the label, accurately encode the phonological form and semantic representation, retain a mapping between these representations, and generalize the mapping to novel exemplars. Children have considerable preexisting knowledge in each of these domains and leverage this knowledge when learning new words. Less is known, however, about whether and how toddlers make use of this emerging knowledge when learning new words.

Regularities within the phonological system permit learners to discover patterns in their native language. One prominent phonological regularity is phonotactics: restrictions on how sounds can be combined at different locations within syllables and words. Phonotactic regularities include both the legality and probability of particular phoneme combinations. For example, the sound sequence /ts/ is permissible in Greek at the beginning of the word (e.g., /tsaɪ/), but only at the end of the word in English (e.g., /kæts/).

Infants' knowledge of native language phonotactics has been demonstrated through 9-month-olds' listening preferences: Infants prefer high-probability over low-probability syllables (Jusczyk, Luce, & Charles-Luce, 1994), unfamiliar words conforming to native language phonotactic patterns over those that do not (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993), and speech samples containing phonotactically legal word offsets over those containing illegal word offsets (Friederici & Wessels, 1993). Infants also use this information to help them segment the speech stream (Mattys & Jusczyk, 2001), even in the absence of other cues (Friederici & Wessels, 1993), and weigh phonotactic cues more heavily than statistical cues (Johnson & Jusczyk, 2001) by 9 months of age. Together, these studies show that, from a very young age, infants show sensitivity to native language phonotactics.

Both infants and adults rapidly learn novel phonotactic regularities in lab tasks (Dell, Reed, Adams, & Meyer, 2000; Finley & Badecker, 2009; Goldrick, 2004; Jusczyk, Goodman, & Baumann, 1999; Onishi, Chambers, & Fisher, 2002). For example, Chambers, Onishi, and Fisher (2003) familiarized 16.5-month-old infants with consonant–vowel–consonant syllables in which a set of arbitrary consonants were artificially restricted to onset (e.g., /b, k, m, t, f/) or coda (e.g., /p, g, n, tʃ, s/) position. Infants subsequently discriminated novel "legal" syllables (conforming to the

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familiarization stimuli) from “illegal” syllables that violated the experimental constraints. These results, along with findings from Chambers, Onishi, and Fisher (2011), show that by 16.5 months of age, infants can rapidly learn first-order (wherein one phoneme is restricted to a syllable position) and second-order (wherein one phoneme is restricted to a position dependent on an adjacent phoneme) segment-based constraints. Infants are also able to learn feature-based first-order constraints (e.g., voiced consonants restricted to syllable initial position) and second-order constraints (e.g., nasal vowels followed by fricative consonants; Cristià & Seidl, 2008; Saffran & Thiessen, 2003; Seidl & Buckley, 2005; Seidl, Cristià, Bernard, & Onishi, 2009).

While infants as a group are able to learn novel phonotactic patterns, results from Graf Estes, Gluck, and Grimm (2016) suggest the presence of striking individual differences. Using a perception training paradigm similar to Chambers et al. (2003, 2011), they found that whereas 18- to 19-month-old infants with smaller vocabularies can learn novel patterns that violate native language phonotactics (e.g., word-onset consonant clusters /ts, pw, fn, or ʃl/), infants with larger vocabularies do not, even when controlling for general cognitive processing abilities. Graf Estes et al. suggest that infants with larger vocabularies have more robust phonotactic knowledge of their native language, which interferes with their ability to learn the conflicting nonnative phonotactic patterns. Although the directionality of these findings is unclear (does vocabulary size influence phonotactic learning, or vice versa), this study highlights possible relationships between infants’ detection of language-specific phonotactic patterns and their vocabulary development.

Infants’ emerging phonotactic knowledge also influences word learning in the lab. For example, MacKenzie, Curtin, and Graham (2012) found that 12-month-old infants are better at mapping objects to labels that conform to native language phonotactics than labels that violate native language phonotactics. This pattern of results is consistent with findings from studies with older infants and young children (Graf Estes & Bowen, 2013; Graf Estes, Edwards, & Saffran, 2011; Storkel, 2001), suggesting that infants’ and children’s knowledge of their native language (e.g., phonotactics) constrains novel word learning.

As in the phonotactic learning literature, the evidence suggests that there are individual differences in the degree to which native language phonological regularities influence novel word learning. Graf Estes et al. (2011) trained 18-month-old infants on a pair of phonotactically legal novel word labels (e.g., “dref”) or phonotactically illegal labels (e.g., “dlef”) mapped onto objects. Although infants with smaller vocabularies learned both types of words equally well, infants with larger vocabularies only succeeded at learning words when the labels were phonotactically legal. These results were striking; it is unusual to observe that infants with smaller vocabularies outperform those with larger vocabularies in a word learning task. The authors argued that the pattern of effects was the result of differences in native language knowledge. Because infants with larger vocabularies have more robust knowledge of the sound properties of their native language, they experience greater difficulty when novel words conflict with that knowledge. Note that these findings are parallel to those described earlier, suggesting group differences such that infants with larger vocabularies have stronger representations of native language phonotactics (e.g., Graf Estes et al., 2016). They are also broadly consistent with evidence suggesting that older infants—who presumably know more about the sound structure of their native language—are less likely to learn words that violate native language phonotactics than younger infants (e.g., Vukatana, Curtin, & Graham, 2016).

In summary, infants’ knowledge about the sound structure of their native language, including its phonotactic regularities, provides a foundation for word learning (e.g., Gonzalez-Gomez, Poltrock, & Nazzi, 2013; Graf Estes, 2014; Graf Estes & Bowen, 2013; Graf Estes et al., 2011; MacKenzie et al., 2012; Saffran & Graf Estes, 2006; Werker & Curtin, 2005). This literature indicates that sensitivity to native language phonotactics constrains novel word learning. However, age- and vocabulary-related differences suggest substantial variability in this process, such that greater native language knowledge impedes the acquisition of patterns and words that violate that knowledge.

One important outstanding question relates to the depth of phonotactic knowledge required to influence word learning. Infants’ and children’s knowledge of native language phonotactics influences novel word learning, both in the native language and in the lab (Graf Estes & Bowen, 2013; Graf Estes et al., 2011; Hay, Graf Estes, Wang, & Saffran, 2015; MacKenzie et al., 2012; Storkel, 2001). Furthermore, infants are able to rapidly learn novel phonotactic patterns in the lab (e.g., Chambers et al., 2003, 2011). However, it remains unknown whether new phonotactic knowledge—of the sort acquired in laboratory phonotactic learning studies—affects word learning. Does even fragile knowledge of sound regularities influence the words that infants can learn? Or must phonotactic knowledge be much more deeply entrenched to impact label–object mapping? To date, no research has examined whether and how novel phonotactic patterns affect novel word learning. This question is of interest from a theoretical perspective: Are nascent word forms influenced by very recent experience (as in the lab), or are months or years of native language exposure required? It is also of interest from an applied perspective: Can brief exposure to sound patterns (as in the lab or in an intervention setting) influence how well young children learn new words? Because prior studies have not connected lab-based phonotactic learning and lab-based word learning, the answers are unclear. It is possible that significant accumulated experience with sound patterns is needed to influence word learning. Alternatively, the literature on statistical learning suggests that even a few minutes of exposure to sound patterns influences the label–object pairs that infants are most likely to learn (e.g., Graf Estes, Evans, Alibali, & Saffran, 2007; Hay, Pelucchi, Graf Estes, & Saffran, 2011; Lany & Saffran, 2010, 2011).

Prior studies examining the influence of phonotactics on word learning have manipulated the legality or probability of native language phonotactic patterns (Graf Estes & Bowen, 2013; Graf Estes et al., 2011, 2016; MacKenzie et al., 2012; Storkel, 2001). The use of native language patterns complicates the interpretation of results suggesting individual differences based on the size of toddlers' vocabularies. The relationship between phonotactics and vocabulary size could be driven by correlations with native language exposure: Children with greater language exposure have more opportunities to learn both phonotactics and new words. Alternatively, some children may be inherently better at learning phonotactic patterns, and these differences may lead to subsequent differences in vocabulary size. Studies using sound patterns that conflict with native language structure cannot distinguish between these accounts. For native speakers of the same language, items that are legal or frequent cannot be otherwise; "dref" will always be legal in English, and "dlef" will not. These considerations limit the conclusions that can be drawn regarding the relationship between infants' vocabulary size and their phonotactic knowledge.

The current study asked whether exposure to word forms that follow a novel phonotactic pattern influences novel word learning for labels that either conform to or violate that pattern. To address this issue, we developed a word learning task that was preceded by exposure to a list of words that all followed a simple phonotactic pattern. In the familiarization phase, toddlers listened to a list of bisyllabic nonsense words that all began with the same phoneme (either /b/ or /k/, counterbalanced across participants), without any objects present. Immediately after familiarization, they were taught four novel label–object pairs; none of the labels for the novel objects had been presented during the familiarization phase. Two of the labels were consistent with the novel pattern heard during familiarization, and two were inconsistent with the pattern heard during familiarization. Word learning was then assessed using the looking-while-listening (LWL) procedure (Fernald, Zangl, Portillo, & Marchman, 2008). On each trial, images of two objects were displayed on a screen, and one of the objects was labeled. Prior studies combining a familiarization phase with a novel word learning phase (Graf Estes et al., 2007; Hay et al., 2011) tested 17-month-old infants, but only included two novel label–object pairs. Because our design required participants to learn four novel label–object pairs, we chose to test slightly older toddlers (22-month-olds).

We predicted that toddlers would be more successful in learning novel label–object pairings when the label was consistent with the novel phonological pattern from the familiarization phase rather than inconsistent with the familiarized pattern. In prior research, the impact of native language phonotactics was greater for infants with larger compared to smaller vocabularies (Graf Estes et al., 2011). Therefore, we predicted that the effect of consistency between the novel phonotactic pattern and the novel labels would be greater for toddlers with larger vocabularies compared to their peers with smaller vocabularies.

Method

Participants

The final sample included 41 monolingual English-learning toddlers (23 girls) with a mean age of 21.9 months (range: 21.0–23.1). Parents reported that toddlers were born full term, had normal hearing and vision, heard less than 10 hr per week of a language other than English, and did not currently have an ear infection. An additional 21 toddlers were excluded from analyses due to experimenter error (two), technical error (five), failure to complete the experiment (five), or too much missing data (nine). Participants with too much missing data were those who had more than half of the test trials excluded from one or both of the conditions (see Quantifying Fixations section below). Participants were recruited from a database of interested families living in or near a midsized city in the midwestern United States. The demographics of the final sample included 38 toddlers who were Caucasian, two who were Asian, and one who was African American.

Procedure

Each session began with a 5-min briefing, in which the experimenter described the procedure, answered questions, and obtained written consent from the caregiver, while the toddler became acclimated to the lab environment. The toddler and their caregiver were then seated in a sound-attenuated booth where the toddler completed the experimental task. Afterwards, their caregiver completed demographic and vocabulary questionnaires.

Measure of Vocabulary

Productive vocabulary was measured via parental report using the MacArthur–Bates Communicative Development Inventory Short-Form Level II (Fenson et al., 2000). We chose to measure expressive vocabulary rather than receptive vocabulary based on prior studies of novel word learning (e.g., Bion, Borovsky, & Fernald, 2013; Law & Edwards, 2015). Indeed, the literature suggests that children's expressive vocabulary is more robustly related to individual differences in novel word learning than their receptive vocabulary (see Pomper & Saffran, 2018). The productive measures obtained from the MacArthur–Bates Communicative Development Inventory were utilized in the current experiment to be consistent with the primary vocabulary measure used across studies of infant phonotactic word learning (see Graf Estes et al., 2011, 2016; Mackenzie et al., 2012). We obtained scores for all but one toddler in the final sample of participants. Out of the 100 words on the checklist, toddlers had an average productive vocabulary of 48.4 words (range: 5–88, $SD = 21.3$), which corresponded to an average ranking in the 47th percentile (range: 1–90, $SD = 29$).

Measure of Word Learning

Toddlers were seated on their caregiver's lap approximately 3 ft from a 55-in. LCD screen in a sound-attenuated booth. Visual and auditory stimuli were presented on the screen using Python. Each of the three phases (familiarization, referent training, and test) began immediately after the completion of the prior phase; the entire procedure lasted approximately 7 min. To eliminate bias, caregivers wore blacked-out glasses and the experimenter was blind to familiarization condition. Eye gaze was recorded using a digital camera mounted below the screen.

Familiarization

Each list consisted of 30 trochaic, bisyllabic novel words with varying syllable structures (e.g., consonant–vowel–consonant–vowel, consonant–vowel–consonant–vowel–consonant). For the first list, all novel words were /b/-initial; in the second list, all novel words were /k/-initial (see Table 1). Participants were randomly assigned to either /b/-initial or /k/-initial familiarization. The list of words was presented once with 500 ms of silence between words (total duration of approximately 45 s). Words were recorded by a female native English speaker using an infant-directed register.

Referent Training

Immediately after familiarization, toddlers were taught the names of four novel objects (see Figure 1). On each trial, a single object appeared on either the left or right side of the screen, briefly moved up and down, and was labeled twice. Trials lasted 5.5 s. Each novel object appeared in four trials and therefore was labeled eight times in total. Trials were arranged into four blocks of five trials each. A 7-s filler cartoon was presented between blocks to keep children engaged.

Novel objects were selected from the Novel Object and Unusual Name Database, 2e (Horst & Hout, 2016). The stimuli in this database are normed for their novelty and visual features. We chose four novel objects that were visually distinct from one another and roughly matched for visual salience, and we edited them in Adobe Photoshop to eliminate any shared visual features (e.g., color).

Table 1. Familiarization sets for the two counterbalanced conditions (using the International Phonetic Alphabet).

Condition 1 words: /b/-initial		Condition 2 words: /k/-initial	
bedɛf	bilu	kedɛf	kilu
beɪmuθ	baɪsaʊ	keɪmuθ	kaɪsaʊ
boveɪz	bɛzi	koveɪz	kɛzi
baɪlɑn	bote	kaɪlɑn	kote
buθɑm	budoɪ	kuθɑm	kudoɪ
bisog	bugo	keɪsog	kugo
bɪfɛt	blpeɪ	kɪfɛt	klpeɪ
baʊvus	baʊvi	kaʊvus	kaʊvi
bɪstof	beɪldɑ	kɪstof	keɪldɑ
baɪgdeɪp	baɪpθoɪ	kaɪgdeɪp	kaɪpθoɪ
bɑntuʃ	beɪngaʊ	kɑntuʃ	keɪngaʊ
biltor	baɪgdɛ	kiltor	kaɪgdɛ
bɪntɛf	biftu	kɪntɛf	kiftu
baʊspot	bospeɪ	kaʊspot	kospeɪ
beɪmpoɪd	bʌnso	keɪmpoɪd	kʌnso

Auditory stimuli consisted of four novel labels. All labels were embedded in carrier phrases (e.g., "Look at the…"; Fennell & Waxman, 2010; Fernald & Hurtado, 2006). Two of the novel labels were /b/-initial ("baftoo" and "beepaug"), and two of the novel labels were /k/-initial ("koovai" and "kothar"). All novel labels followed a trochaic stress pattern, which matched the stress pattern from the familiarization set. None of the novel words that were used as labels in referent training was included in the familiarization set. For toddlers exposed to /b/-initial words during familiarization, "baftoo" and "beepaug" were consistent with the familiarized pattern and "koovai" and "kothar" were inconsistent; the pattern was flipped for toddlers exposed to /k/-initial words during familiarization.

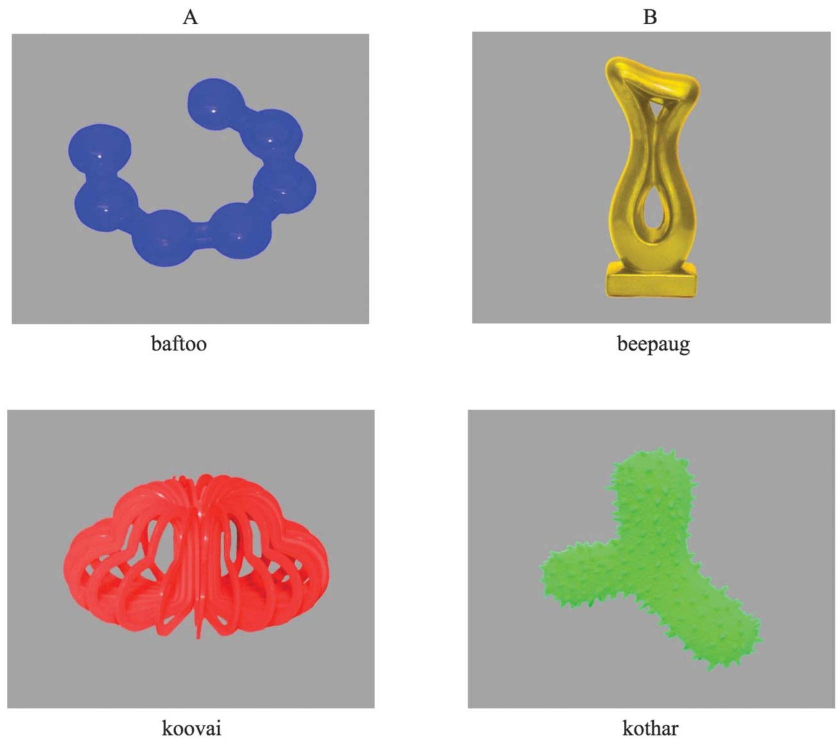
Each block of trials began with a familiar object trial (ball, shoe, cat, or dog) followed by a trial for each novel object. Familiar objects were included to orient toddlers to the naming aspect of the task. These nouns were chosen to be highly familiar objects to toddlers in this age range. We included labels that were both consistent and inconsistent with the phonological pattern in the training set to ensure that the familiar words would neither reinforce the training set (i.e., if all the familiar words started with /k/ or /b/) nor counteract the training set (i.e., if none of the familiar words started with /k/ or /b/).

Test

Immediately after referent training, toddlers' retention of the label–object mappings was tested using the LWL procedure (Fernald et al., 2008). The same female native speaker recorded tokens of each sentence, which were edited in Praat to match duration (carrier: 739 ms; target: 812 ms) and intensity (65 dB). The images of the four objects were identical to those used during the referent training phase.

There were two types of test trials. On consistent trials, the labels for both the target and distractor objects followed the phonotactic pattern trained during familiarization. On inconsistent trials, the labels for both the target and distractor objects were inconsistent with the phonotactic pattern trained during familiarization. Thus, for example, a consistent trial for a toddler who had been familiarized with the /b/-initial pattern would consist of the two objects with /b/-initial labels, one of which would be labeled. This same trial would be an inconsistent trial for a toddler who had been familiarized with the /k/-initial pattern. The objects were yoked such that the two objects with /b/-initial labels were always paired together and the two objects with /k/-initial labels were always paired together. Thus, half of the trials for each participant tested label–object pairs that were consistent with the phonological regularity, and the other half tested label–object pairs that were inconsistent with the phonological regularity.

Figure 1. Images and names for the four novel objects used in the current experiment. The images are all from the Novel Object & Unusual Name Database (Horst & Hout, 2016).



On each test trial, stationary images of two objects were displayed on the left and right sides of the screen in silence (2 s). The images then remained on the screen in silence for 1 s. Toddlers then heard a sentence labeling one of the objects followed by a generic attention-getter phrase (e.g., "Find the baftoo. Check that out!"). There were eight consistent and eight inconsistent trials for each toddler (counterbalanced such that /k/-initial words were consistent and /b/-initial words were inconsistent for half of the toddlers, and vice versa for the other half).

As in the referent training phase, trials were arranged into four blocks of five trials. Each block of trials began with a familiar object trial followed by trials for each novel object. Each novel object appeared equally as often as the target and distractor and appeared as a target on the left and right sides.

Quantifying Fixations

Toddlers' fixations were video-recorded and coded offline frame by frame (every 33 ms) by two trained coders. Coders were blind to the condition and target word/location for each trial. Eighty-five percent of the videos were coded by the primary coder, and 15% of the videos were coded by the secondary coder. To determine reliability, 25% of the videos coded by the primary coder were recoded by the secondary coder. On average, both coders agreed on gaze location for 96% of all frames and agreed on shifts in gaze for 92% of all shifts.

Word learning accuracy was quantified by measuring children's fixations of the target object during a window from 600 to 2,100 ms after the onset of the target word. This window begins later than the standard LWL window (300 to 1,800 ms), because unlike most LWL experiments, the target and distractor objects in the current experiment shared the same onsets (/b/-initial label–object pairs were always displayed together and /k/-initial label–object pairs were always displayed together). Prior research suggests that 24-month-olds' fixations to the target object are delayed by approximately 300 ms when the onsets of the target and distractor items overlap phonetically (e.g., "dog" and "doll") compared to when they do not overlap (e.g., "dog" and "ball"; Swingley, Pinto, & Fernald, 1999). We thus delayed the start of the analysis window to reflect overlapping onsets. Trials were excluded if the toddler was not fixating either object for more than 33% of the critical window or if the toddler or caregiver was speaking during the critical word.

Accuracy was measured by examining the time course of fixations to the target object on test trials. Fixations to the target object were calculated as empirical log odds in order to accommodate the binary nature of our data—at each time point, children were looking at either the target or the distractor object (Barr, 2008). Changes in the time course of toddlers' empirical log odds of fixating the target were quantified using growth curve analysis. When using orthogonal polynomials, each time term quantifies different aspects of the time course. The intercept is centered and quantifies toddlers' overall log odds of looking to the target (i.e., averaged across the entire window). Linear time captures the monotonic change in toddlers' log odds over time (i.e., the average increase in toddlers' fixations to the target every 33 ms). Quadratic time quantifies the symmetric rise and fall around the central inflection point (i.e., the peak of the asymptote). Cubic time captures the rise and fall around inflection points around the tails (i.e., changes at the beginning and end of the window).

The within-subject effect of condition was centered (contrast coded as −0.5 for consistent and 0.5 for inconsistent trials). Unless otherwise specified, the between-subjects effect of vocabulary was also centered (by subtracting the group average from each participant's score). All models included the maximal random effects structure (Barr, Levy, Scheepers, & Tily, 2013). Models were fit using maximum likelihood estimation. Tests of significance were performed using model comparisons. A model containing all of the fixed effects was compared with reduced models that removed individual fixed effects using a likelihood ratio test with log-likelihood (−2LL), which is distributed as χ^2 with the degrees of freedom corresponding to the difference in the number of parameters included in each model. All analyses were carried out in RStudio (Version 1.1.414) using the lme4 package (Version 1.1-17).

Results

Before testing our hypotheses, we first examined whether the time course of toddlers' fixations to the target on test trials was the same in both of our counterbalanced conditions (/b/-initial vs. /k/-initial). The effect of exposure (contrast coded as −0.5 for /b/-initial familiarization and 0.5 for /k/-initial familiarization) was not significant for any time terms, *p*s > .20. Moreover, the effect of the Exposure × Condition interaction was not significant for any time terms, *p*s > .45. These results indicate that, as expected, exposure to the /b/ and /k/ phonological regularities had the same effect on toddlers' word learning. In all subsequent analyses, we collapsed across the two types of familiarization.

Our first hypothesis was that exposure to a novel phonological regularity would facilitate learning of object labels that were consistent with the familiarized pattern. We predicted that toddlers would be more successful in learning label–object pairings that were consistent with the pattern presented during familiarization compared to label–object pairings that were inconsistent. Figure 2 shows the time course of toddlers' fixations to the target object in the consistent and inconsistent conditions. When collapsing across both conditions, there was a significant effect of the intercept, $b = 0.27$, $\chi^2(1) = 16.1$, $p < .001$; linear, $b = 1.03$, $\chi^2(1) = 8.0$, $p < .01$; and quadratic, $b = -0.38$, $\chi^2(1) = 4.0$, $p < .05$, time terms. However, the effect of condition was not statistically significant for any of the time terms, *p*s > .17. These findings reveal that toddlers learned the novel words—their overall fixations to the target object on test trials were above chance, and their fixations to the target increased over time and reached a peak asymptote before the end of the critical window (i.e., they subsequently declined). Contrary to our hypothesis, however, toddlers' fixations to the target object were not affected by whether or not the label was consistent with the pattern heard during the familiarization phase.

Our second hypothesis was that the impact of the novel phonological regularity on word learning would be moderated by toddlers' vocabulary sizes. Specifically, we predicted that word learning in toddlers with larger vocabularies would be more affected by the novel phonological regularity than their peers with smaller vocabularies. Figure 3 shows the time course of toddlers' fixations to the target object on consistent and inconsistent trials for a hypothetical toddler with a larger (i.e., 1 *SD* above the group average) versus smaller (1 *SD* below the group average) productive vocabulary. When collapsing across both conditions, there was a significant effect of toddlers' vocabulary on the intercept, $b = -0.01$, $\chi^2(1) = 4.9$, $p < .05$, and linear, $b = 0.04$, $\chi^2(1) = 5.4$, $p < .05$, time terms. Compared to toddlers with smaller vocabularies, toddlers with larger vocabularies had lower overall rates of fixating the target object but showed greater increases in their fixations to the target over time (i.e., from the beginning to the end of the critical window). The effect of vocabulary on the intercept was qualified by a significant interaction with condition, $b = -0.01$, $\chi^2(1) = 5.1$, $p < .05$. To follow up on this interaction, we recentered vocabulary scores twice, once to be 1 *SD* above the group average (i.e., toddlers with larger vocabularies) and once to be 1 *SD* below the group average (i.e., toddlers with smaller vocabularies), and examined the effect of condition (consistent vs. inconsistent). For toddlers with larger vocabularies, there was a significant effect of condition on the intercept, $b = -0.45$, $\chi^2(1) = 8.6$, $p < .01$. These toddlers had lower overall fixations to the target in the inconsistent compared to the consistent condition. In fact, their overall fixations to the target were significantly above chance in the consistent condition, $b = 0.36$, $\chi^2(1) = 9.3$, $p < .01$, but not in the inconsistent condition, $b = -0.08$, $\chi^2(1) = 0.6$, $p = .44$. For toddlers with smaller vocabularies, however, there was not a significant effect of condition on the intercept for any of the time terms, *p*s > .28. These toddlers' overall fixations to the target object were significantly above chance in both the consistent, $b = 0.40$, $\chi^2(1) = 10.8$, $p = .001$, and inconsistent, $b = 0.43$, $\chi^2(1) = 12.9$, $p < .001$, conditions. Taken together, these results suggest that exposure to the novel phonological regularity during the familiarization phase influenced learning for infants with larger productive vocabularies by hindering their ability to learn labels that were inconsistent with the novel phonological regularity. Exposure to the novel phonological regularity did not impact word learning for infants with smaller productive vocabularies.

Conclusions

We briefly familiarized toddlers with a set of novel words that conformed to a simple phonological regularity: Each word in the set began with the same consonant.

Figure 2. Empirical log odds of fixating the target object as a function of time (in milliseconds) since the onset of the target word and condition (novel label that was either consistent or inconsistent with the novel phonological regularity). Data points are the observed behavioral data (averaged across participants). The lines represent the growth curve fits, and the ribbons around the lines represent ± 1 *SE*. The dotted horizontal line at 0 represents chance (i.e., equal probability of fixating the target vs. the distractor object).

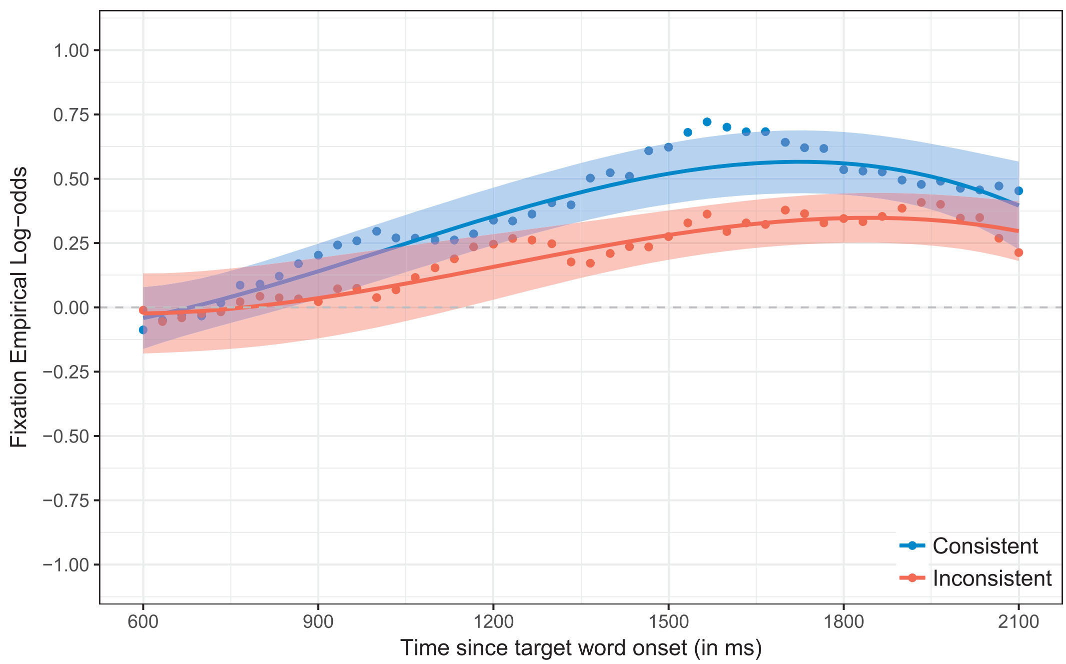
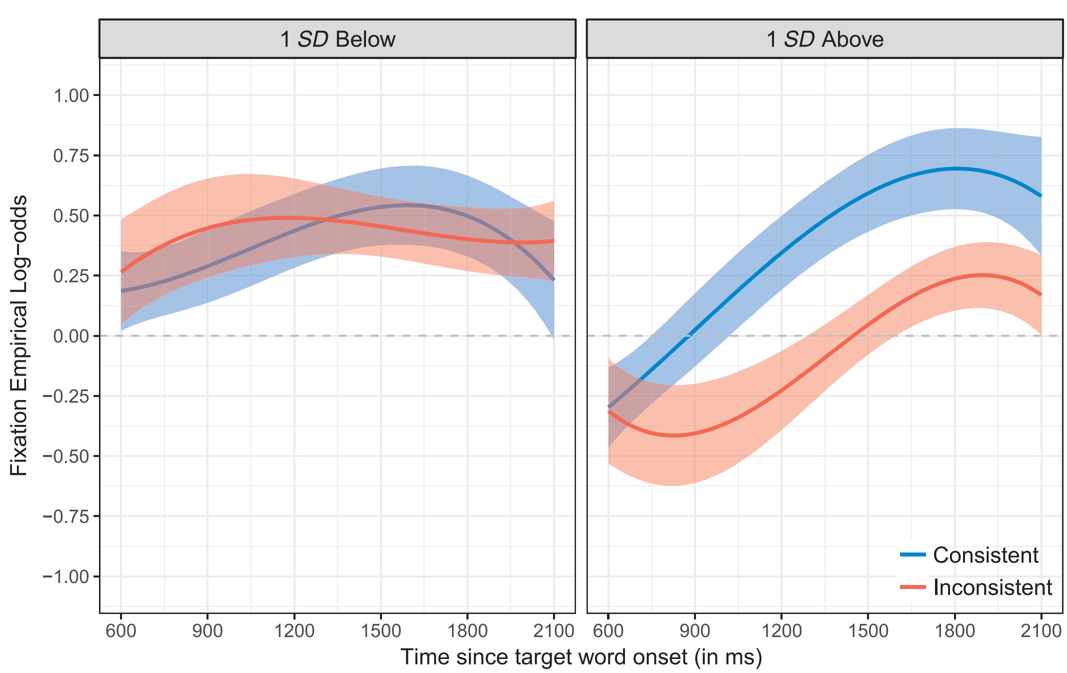


Figure 3. Mean proportion of fixations to the target novel object on test trials averaged across the critical window (600–2,100 ms) as a function of condition (novel label that was consistent or inconsistent with the novel phonological regularity). Data points represent the proportion for each toddler averaged across trials. Error bars represent ± 1 *SE*. The dashed horizontal line represents chance (i.e., 50% or equal looking to both the target novel object and the distractor familiar object).



Toddlers were then exposed to four novel label–object pairs. None of the labels had been included in the familiarization set. Two of the labels were consistent with the phonological regularity (same initial consonant as the familiarization materials), and two of the novel names were inconsistent with the phonological regularity (different initial consonant from the familiarization materials). We found that, as a group, toddlers readily learned label–object pairings that were consistent with the familiarized phonological regularity. The effect of familiarization on word learning, however, was moderated by the size of the toddlers' expressive vocabulary: Toddlers with larger vocabularies only learned the consistent label–object pairings, whereas toddlers with smaller vocabularies learned all label–object pairings.

Although our results are indicative of a similar association between vocabulary size and infants' word learning, they differ from prior research in one important way. Studies by Graf Estes et al. (2011, 2016) were designed to tap infants' knowledge of native language phonotactics, wherein sufficient knowledge of sound structure would interfere with successful learning of illegal phonotactic patterns and words. In the current experiment, infants were exposed to a novel phonotactic regularity and taught novel label–objects that did not violate English phonotactics. It is therefore striking that our brief familiarization influenced infants' learning. As prior research has shown that infants' word learning is influenced by aspects of native language sound structure (Graf Estes & Bowen, 2013; Graf Estes et al., 2011; Hay et al., 2015; MacKenzie et al., 2012; Storkel, 2001), our results provide the first experimental demonstration that exposure to a novel phonotactic regularity may serve to shape infants' expectations of candidate word forms. As our manipulation only affected the word learning performance of infants with relatively larger vocabulary sizes, our findings provide evidence that the process of constraining candidate word forms through experience may be multifaceted. It is therefore imperative that future research continue to examine how infants develop this selectivity and mechanisms underlying individual differences in selectivity.

Children with larger vocabularies typically outperform children with smaller vocabularies in word learning tasks (e.g., Bion et al., 2013; Law & Edwards, 2015). This is not the pattern observed in the current study, which is consistent with prior research in which native language phonological regularities constrained word learning for infants with larger vocabularies, but not for infants with smaller vocabularies (Graf Estes et al., 2011, 2016). In the context of the current research design, the data suggest that toddlers with larger vocabularies successfully learned the novel phonological regularity presented during the familiarization phase, and this knowledge impacted their subsequent word learning. The results are less clear, however, for toddlers with smaller vocabularies who learned all of the label–object pairings, regardless of their consistency with the familiarization stimuli. Equivocal learning in the consistent and inconsistent conditions could be interpreted in multiple ways. It is possible that toddlers with smaller vocabularies failed to learn the novel phonological regularity. Alternatively, toddlers with smaller vocabularies may have learned the regularity but failed to generalize their knowledge to novel labels during the word learning task. As our experimental design necessitated the inclusion of both exposure and novel word learning phases, it was not possible to directly assess toddlers' phonotactic learning. A critical step in future research will be to distinguish between these alternative accounts by directly assessing toddlers' learning of novel phonological regularities outside a word learning task.

In their natural linguistic input, children experience a vastly more complex array of phonological regularities than we could provide in the current experiment. Future research will explore whether exposure to first- and second-order constraints at both the level of the segment and feature (e.g., consonant and syllable combinations) will also affect novel word learning. A wide body of literature on phonotactic learning suggests that infants can successfully learn these patterns but has never explored their role in the context of word learning (Chambers et al., 2003, 2011; Cristià & Seidl, 2008; Saffran & Thiessen, 2003; Seidl & Buckley, 2005; Seidl et al., 2009). It will also be important for future research to explore how different types of exposure (e.g., concentrated vs. distributed, word lists with vs. without associated referents) affect toddlers' novel word learning and whether there is an interaction with phonological complexity. Finally, given the importance of individual differences in the current experiment and elsewhere in the literature, future work should include more varied measures of individual differences (e.g., both receptive and expressive vocabulary). Thus, the current experiment represents an important step, but only the first step, in examining how toddlers' ability to learn phonological regularities impacts word learning.

Our results are consistent with a broad array of research demonstrating that exposure to sound regularities influence toddlers' word learning. Infants track statistical regularities to segment continuous streams of speech containing novel words and use this knowledge to support subsequent word learning (Graf Estes et al., 2007; Saffran, Aslin, & Newport, 1996). Infants learn novel label–object pairings when the label contains high-probability syllable sequences that were present during exposure but do not learn when the label contains syllable sequences that either did not occur or occurred with low probability (Graf Estes et al., 2007; Pelucchi, Hay, & Saffran, 2009; Shukla, White, & Aslin, 2011). Infants not only detect and learn many types of regularities in their linguistic input but also apply this knowledge when learning new words.

Unlike prior research using well-established phonotactic knowledge from infants' native language, our findings reveal that the acceptability of word forms is influenced by learners' ongoing linguistic experiences. Language acquisition is not fully sequential, with children first acquiring knowledge of native language sounds, then sound patterns, then words, and then grammar. Rather, linguistic structures are acquired in an interactive manner, with partial knowledge in one linguistic domain helping to bootstrap the acquisition of knowledge in another linguistic domain (e.g., Morgan & Demuth, 1996; Romberg & Saffran, 2013; Saffran & Graf Estes, 2006; Shukla et al., 2011; Werker, 2018). The current experiment supports the view that children learn multiple components of language in tandem and, in particular, illustrates how learning in one domain (phonotactics) may influence learning in another (word learning).

Selectivity in the sound sequences that constitute viable word candidates promotes more efficient lexical acquisition by allowing children to focus only on those features that are relevant for learning words in their native language. This selectivity is important in more naturalistic word-learning environments when acoustic information may be noisy or inaccessible (due to the presence of background noise, multiple speakers, etc.). Our findings, taken together with prior research observing differences in age (e.g., Hay et al., 2015; Vukatana et al., 2016), vocabulary (e.g., Graf Estes et al., 2011; Storkel, 2001), bilingual status (Graf Estes & Hay, 2015), and referential context (Vukatana et al., 2016), reveal that exposure to phonological regularities affects novel word learning; this effect, however, varies based on both the current context and children's past linguistic experiences. Understanding how all of these factors work together has the potential to provide novel insights into possible interventions that might facilitate word learning in children with language disorders.

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