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Intersecting Constraints on Label Learning: Effects of Age, Label Properties, and Referential Context

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Abstract

This research investigates the development of constraints in word learning. Previous experiments have shown that as infants gain more knowledge of native language structure, they become more selective about the forms that they accept as labels. However, the developmental pattern exhibited depends greatly on the way that infants are introduced to the labels and tested. In a series of experiments, we examined how providing referential context in the form of familiar objects and familiar object names affects how infants learn labels that they would otherwise reject, nonspeech sounds. We found evidence of the development of intersecting constraints: Younger infants (14-month-olds) were more open to learning nonspeech tone labels than older infants (19-month-olds), and younger infants were more open to the influence of referential context. These findings suggest that infants form expectations about labels and labeling contexts as they become more sophisticated learners.

A prominent narrative in early language acquisition is that as infants learn more about the structure of their native language, they become more focused and efficient learners (Graf Estes, Gluck, & Grimm, 2016; Hockema & Smith, 2009; Namy, 2012; Werker & Curtin, 2005). Infants' learning gradually centers on the sounds and symbols that are relevant in the native language and minimizes the weight given to forms that are not used in the language. The narrowing in speech perception and word learning that occurs across development may promote vocabulary acquisition. Perceptual narrowing, tuning speech perception to highlight native language phoneme contrasts, may contribute to the establishment of efficient and flexible phonological representations that serve word learning (Werker & Curtin, 2005). Interpretive narrowing of the forms that are accepted as object labels may also be one of many advances in domain general (e.g., memory) and language-specific (e.g., shape bias; mutual exclusivity) capacities that promote the acceleration of vocabulary growth during the second year of life (McMurray, 2007; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002). The present research investigated changes in the openness of early word learning. We explored how the developmental narrative about the construction of word learning constraints is intimately linked to how learning is probed.

Early studies of infants' openness in label learning compared infants' learning of verbal labels to gestures and nonspeech sounds. Namy and Waxman (1998) presented 18- and 26-month-olds with words or gestures as labels for object categories in an interactive task. The experimenter engaged with the infant with two objects from a single category (e.g., vehicles: toy car, van) and labeled them with the same novel label while the infant was attending (e.g., "Look at the *blik*" or "Look at this. [gesture: knocking motion]"). During testing, the experimenter labeled one of the original training objects again, then asked the infant to find another (label) from a pair of objects containing another exemplar from the same category and an unrelated object. They found that 18-month-olds accepted words and gestures as category labels, but 26-month-olds only learned the word labels (for additional demonstrations see Namy, Campbell, & Tomasello, 2004; Suanda, Walton, Broesch, Kolkin, & Namy, 2013). Graham and Kilbreath (2007) also found that 14-month-olds took advantage of gesture labels to make inferences about objects' nonobvious properties, but 22-month-olds only used words, not gestures, to promote generalization. In related research, Woodward and Hoyne (1999) examined infants' learning of non-speech sounds (e.g., beeps, squeaks, whistles) paired with objects in a socially interactive task. While the infant attended to the object, the experimenter presented the sound (e.g., "Look at this. [squeak]"). They found that 13-month-olds, but not 20-month-olds, learned the sound-object associations. Namy (2001) also found that when 17-month-olds were given referential support, they learned nonspeech sounds (e.g., glissando, 2-tone beep) as category labels. Across these findings, there is a developmental progression: infants are initially open to learning words, nonspeech sounds, and gestures as labels. Around their second birthday, infants' acceptance of label forms narrows.

However, label learning depends greatly on the context in which the labels are presented (Werker & Curtin, 2005). Campbell and Namy (2003) found that when the experimenter produced labels while engaged in a social interaction, using common labeling phrases, 18-month-olds learned words and nonspeech labels (but see Puccini & Liszkowski, 2012). In contrast, infants did not learn words or nonspeech labels when they were presented over a baby monitor with the timing of labeling disconnected from the timing of the social interaction. Older infants (24-month-olds) could also be influenced to accept nonspeech labels in a task that established the within-context relevance of the unusual forms, but not without the context (Henderson, Graham, & Schell, 2015). These findings indicate that the form of a label is not the only factor affecting whether infants will learn it; infants use experience with typical naming events to guide learning. Further support for this idea comes from Namy and Waxman's (2000) demonstration that although 17-month-olds accepted gesture labels for categories when the labels were presented in both naming phrases ("We call this one [gesture label].") and in isolation with attention-eliciting phrases (e.g., "Look here! [gesture label]"), they only accepted words as labels for categories when they were presented in naming phrases. After brief training with isolated familiar words, infants could also learn novel word labels when presented in isolation. One conclusion from these lines of work is that as infants accumulate knowledge of how words and labeling contexts function, they become more selective about the conditions that support word learning. When conditions fit with their prior expectations because of the form of the label or the labeling

environment, learning occurs more readily than when conditions are inconsistent with infants' prior experience.

Namy and colleagues (e.g., Namy et al., 2004; Namy & Waxman, 1998; Suanda et al., 2013) and Woodward and Hoyne (1999) demonstrated important developmental changes in how infants learn during rich social interactions. Recently, several investigators have explored the flexibility of label learning in simplified labeling environments. Although the developmental timeline is different from the prior work on gesture and nonspeech labels, the concept of interpretational narrowing in the forms that infants accept has been replicated. Many studies investigating the forms that infants accept as labels have used versions of the Switch paradigm (Hay, Graf Estes, Wang, & Saffran, 2015; MacKenzie, Graham, & Curtin, 2011; May & Werker, 2014). In this task, the infant views an object on a screen and hears repetitions of the label as the object moves (Werker, Cohen, Lloyd, Casasola, & Stager, 1998). The labels are typically presented as isolated tokens (e.g., *neem…neem…neem*) and objects are displayed through video recordings of the object on a black or white background. To test infants' knowledge, there are two types of test trials. On Same trials, the infant views the original label-object pairings from training; on Switch trials, the infant views the same objects, but the labels are swapped (i.e., object 1 + label 2; object 2 + label 1). If infants learned the labels, they should look longer on the Switch trials in which the learned associations are violated. The goal of the Switch task is to tap the fundamental ability to associate a word form with an referent (Werker et al., 1998). Although the task lacks social interaction and does not test the ability to generalize and extend a label, it measures an essential early building block of lexical development, namely, the ability to form label-object associations.

Using the Switch task, Hay et al. (2015) revealed developmental change in the linguistic forms that infants accept as labels. They tested infants' learning of object labels that differ in pitch contour. As monolingual English learners, the participants had no experience with tonal languages, in which the pitch contour that a word takes affects its meaning. For example, in Mandarin Chinese there are four lexical tones: level, rising, dipping, and falling. The syllable *ma* has four different meanings when produced with these different tones. Although nontonal languages, like English, use pitch to convey important social and affective information, pitch contour contrasts do not signal differences in word meaning; the word *ball* has the same referent when spoken with a rising or a falling pitch. Hay et al. (2015) examined the developmental course of the interpretation of pitch contour in 14-, 17-, and 19-month-olds. Using the Switch task, infants were trained on pitch contour minimal pairs; the syllable *ku* was produced with a rising tone paired with one object and produced with a falling tone paired with a second object. Only the 14-month-olds learned the label-object pairings. The 17- and 19-month-olds showed no evidence of learning the labels that relied on this non-native contrast (see also Graf Estes & Hay, 2015 for evidence with bilinguals). Using a more referential task that incorporated labeling phrases (e.g., "Look here! It's a *leng*!") and familiar objects (e.g., book, ball) during training, Singh, Hui, Chan, and Golinkoff (2014) found that 18-month-olds were open to interpreting pitch as means to contrast words (i.e., they treated a change in pitch similar to a change in a phoneme), but 24-month-olds were not. Thus, we have evidence of interpretational narrowing for pitch contours across two lines of work, but the timing of this narrowing may depend on the

methods used to probe what infants learn. Although there were several differences across the Hay et al. and Singh et al. experiments (see Graf Estes & Hay, 2015 for additional discussion), one possible interpretation is that when the labeling context is richer, infants are more open to accepting a label form that they might otherwise reject.

Further evidence for shifts in the label forms that infants accept comes from experiments by May and Werker (2014) who examined infants' learning of a pair of labels containing another type of non-native linguistic contrast, click consonants. The two labels were CV words from the Khosian language N|uu. Each incorporated a distinct click phoneme (i.e., a postalveolar click and a lateral-alveolar click) with a vowel. The English-learning 14- and 20-month-old participants, who had no prior experience with click contrasts, heard the labels paired with objects. May and Werker (2014) found that neither group of infants learned the labels under the typical Switch task conditions. However, the pattern of learning changed when infants received some referential support. When the novel object labeling was preceded by a training phase in which infants viewed a series of familiar objects and heard their labels (e.g., baby, dog, car, kitty), 14-month-olds learned the click labels. The 20-month-olds with relatively small vocabularies also learned the labels, but those with larger vocabularies did not (see also Singh, 2018, for evidence with bilinguals). These findings suggest that infants whose language skills are less advanced are more open to a range of labels, but also that they are more open to the influence of referential context than infants with more advanced language skills. Furthermore, though the Switch task with referential context initially demonstrated that support of this nature can help 14-month-olds attend to native language phoneme contrasts (Fennell & Waxman, 2010), May and Werker's (2014) findings show that referential support can encourage infants to attend to phonemic details that are not part of the native language. Labeling context can support openness to symbolic forms that would not otherwise be present.

A similar pattern of interaction of label properties and labeling context is observed in studies of infants' ability to map objects to labels that vary in their phonotactic probability. These experiments tested infants' learning of labels that consist of native language phonemes presented in phoneme combinations that either do not occur in the language (e.g., *ptak*, *svet*; "illegal" labels) or labels that were consistent with native language (English) phoneme combinations (e.g., *plok*, *snet*). Using the classic Switch design, MacKenzie, Curtin, and Graham (2012; see also MacKenzie et al., 2011) demonstrated that 12-month-olds readily learned object labels that were consistent with English phonotactics, even if they contained non-native phonetics, but failed when the labels included sound combinations that were illegal in English. However, infants performed differently when they were presented with the same labels in a Switch task with additional referential context. Following brief exposure to familiar objects and labels, 12-month-olds also learned the illegal labels (MacKenzie, Graham, Curtin, & Archer, 2014). Furthermore, there were developmental differences in susceptibility to exposure to familiar words. A subsequent experiment revealed that 16-month-olds accepted phonotactically illegal labels in a Switch task with referential context (but not without the context). In contrast, 20-month-olds did not learn the illegal labels even after receiving the context cues (Vukatana, Curtin, & Graham, 2016). These findings using the Switch task are broadly consistent with Graf Estes, Edwards, and Saffran's (2011) findings using another looking-based measure of learning (i.e., looking while listening;

Fernald, Zangl, Portillo, & Marchman, 2008). They found that overall 18-month-olds rejected phonotactically illegal labels in a task that incorporated naming phrases (e.g., "Look at the *sroob*!") and familiar objects (e.g., ball, shoe). However, infants with smaller vocabularies within the group showed reliable recognition of the labels that violated native language sound patterns. Thus, across studies, infants exhibit developmental differences in openness to phonotactically illegal labels, but the openness is affected by the conditions in which the labels are taught and tested.

Across two decades of studies of infants' learning, there is evidence of an interaction between label properties, context of presenting object labels, and development. Werker and Curtin (2005) addressed the significance of the interaction of label, context, and development in their Processing Rich Information from Multidimensional Interactive Representations model (PRIMIR; see also Curtin, Byers-Heinlein, & Werker, 2011). The framework originally focused on the development of speech perception and word learning, providing valuable explanations for why infants succeed in auditory perception tasks when they fail in word learning tasks. Werker and Curtin argued that one cannot understand the representations that infants form separately from the tasks they are performing in the moment. The present research builds from this perspective to investigate the phenomenon that younger infants are more accepting of atypical label types than older infants. However, the point at which infants show constraints on learning depends on whether the task is interactive (e.g., Namy & Waxman, 1998; Woodward & Hoyne, 1999), involves recorded objects and labels (e.g., Hay et al., 2015; MacKenzie et al., 2012), or includes familiar labeling context information (e.g., Singh et al., 2014; Vukatana et al., 2016). The present research extends this line of inquiry to examine how far referential support can sway word learning. Do infants use referential context as a forceful but imprecise tool to promote label learning, even for labels that are not linguistic? Novice learners may use referential support to overgeneralize about the forms that can be accepted as object labels. In contrast, as infants learn about the forms that labels take and the contexts in which labeling occurs, they may develop constraints that diminish the broad effects of referential context.

We investigated the interplay of the nature of the acoustic form of labels, the presence of referential context, and age. In Experiments 1 and 2, we examined developmental differences in learning nonspeech labels at 14 versus 19 months. In Experiment 3, we examined whether activating referential context information can encourage infants to learn nonspeech labels.

Experiment 1

Experiment 1 tested infants' label learning using nonspeech tones. To allow for a comparison with prior work on label learning of linguistic tones, the nonspeech labels shared a prosodic property with spoken labels. The labels were created by imposing rising and falling pitch contours, derived from Mandarin Chinese lexical tones, on synthesized nonspeech tones. Infants heard the nonspeech tone contour labels in the Switch task. They viewed a pair of objects, one at a time, and heard repetitions of each label. After infants reached the habituation criterion, the label-object pairings were switched (object 1 played with label 2). If infants learned the original label-object pairings, they should look longer on

test trials in which the pairings are violated. There was minimal referential support for the labels. Therefore, in the present experiment, we predicted that infants would not learn the tone contour labels because infants have shown constraints in similar tasks, rejecting foreign language sounds and phonotactically illegal spoken labels (MacKenzie et al., 2012; May & Werker, 2014). We tested 14- and 19-month-old infants to align with prior demonstrations of the emergence of narrowing and the effects of referential context on label learning (Hay et al., 2015; May & Werker, 2014).

Method

Participants—Nineteen 14-month-old infants (9 females; M = 14.31 months; SD = 0.41; range = 13.77 – 14.93) and twenty 19-month-old infants (9 females; M = 19.64 months; SD = 0.44; range = 18.86 – 20.47) participated in the label learning task in Experiment 1. Infants in both groups were born full term and did not have vision or hearing problems, according to parent report. All infants were tested in northern California and primarily heard English. No infants were exposed to tonal languages. Three 14-month-olds heard a second language for up to 4% of their overall language exposure: Spanish (2), German (1). Before conducting the full analyses, we examined the data for outliers. Two 14-month-olds and one 19-month-old were found to have looking time preference scores greater than 2 Standard Deviations from the Mean and were excluded from final analyses. Thirteen additional infants were excluded due to fussiness or crying (14 months: 2; 19 months: 5), parental interference (14 months: 1; 19 months: 1), excessive movement (14 months: 1; 19 months: 2), and equipment error (19 months: 1).

Stimuli

Objects.: The two novel objects that received nonspeech labels (see Figure 1) were designed to differ in shape, color, and texture to ensure they were readily discriminated. They were identical to stimuli used by Hay et al. (2015). During each trial, the objects moved from side to side on a monitor in front of a black background. The movement was not synchronized with label timing.

Labels.: The label stimuli were designed to be nonlinguistic in nature, but to contrast in a salient and language-relevant perceptual dimension, pitch. One label exhibited a rising pitch, and the other a falling pitch. To create the tone contour labels, we used Praat audio processing software (Boersma & Weenink, 2012) to extract pitch contours from the vowel segment of spoken syllables recorded by a native speaker of Mandarin Chinese producing Mandarin tone2 (rising) and tone4 (falling). The spoken labels were used in prior experiments (Graf Estes & Hay, 2015; Hay et al., 2015). As in prior work using natural speech stimuli, two tokens were used for each label (i.e., two rising, two falling), presented in a pseudorandom order. The rising and falling pitch contours were superimposed on artificial tones synthesized to have the same average frequency (rising → token 1 = 223 Hz, token 2 = 222 Hz; falling → token 1 = 255 Hz, token 2 = 272 Hz) and duration (rising → token 1 = 713 ms, token 2 = 717 ms; falling → token 1 = 716 ms, token 2 = 709 ms) as the vowel segment from each word token. The median pitch for the new recording was then adjusted to match the median pitch for the spoken syllable tokens (rising → token 1 = 258 Hz, token 2 = 276 Hz; falling → token 1 = 215 Hz, token 2 = 209 Hz). Figure 2 illustrates

the pitch contours. During each trial, the labels were repeated with 750 ms of silence between presentations.

Procedure—Infants completed the Switch task in a sound-attenuated booth while sitting on a parent's lap approximately 3′ from a large computer monitor. Parents were instructed to avoid influencing infants' attention and wore headphones playing masking music to prevent unintentional bias. Before the start of the habituation trials, there was one pretest trial showing an animation of a rotating screen while repetitions of the syllable "la" played. The pretest trial was intended to familiarize infants with viewing items on the screen and hearing sounds and to prevent inflated first habituation trials. All objects were displayed on the monitor at approximately infant eye level. Before each habituation and test trial, infants viewed a colorful animation to elicit attention to the screen. On each habituation trial, one object moved vertically back and forth across the monitor while its label played via computer speakers at approximately 65–70 dB. The trial ended when the infant looked away from the screen for more than 1 s or after a maximum of 20 s. Habituation trials were presented in a pseudorandom order with the requirement that an object could not appear more than twice in a row. The habituation criterion was reached when looking time across three consecutive trials dropped below 50% of looking on the initial three habituation trials, or after the infant had viewed 25 trials. Label-object pairings were counterbalanced across infants (i.e., one half of the infants heard the rising tone with object 1 and one half heard the falling tone with object 1).

After habituation, infants completed eight test trials. During the Same trials, infants viewed the original label-object pairs (object 1 + label 1, object 2 + label 2). During the Switch trials, the habituation pairings were violated (object 1 + label 2, object 2 + label 1). Test trials were presented in two blocks of four trials (2 Same, 2 Switch per block) in which a Same trial and Switch trial were presented for each of the two objects. There were eight counterbalanced test orders. If infants learned the label-object pairings during habituation, we anticipated increased looking to the more novel Switch trials over Same trials. Habit 2 software (Oakes, Sperka, & Cantrell, 2015) was used to present the stimuli and record looking time. Infant looking behavior was captured via live video recording and coded in real time by an experimenter blinded to trial type.

Results and discussion

The 14-month-olds met the habituation criterion in a mean of 124.0 s ($SD = 85.2$), across 10.74 trials ($SD = 6.27$). The 19-month-olds met the habituation criterion in a mean of 116.1 seconds ($SD = 56.7$), across 10.15 trials ($SD = 3.76$). There were no significant differences between the ages in number of seconds ($p = .74$) or trials to habituate ($p = .72$).

To test whether infants displayed evidence of learning the nonspeech tone contour labels, we performed a 2 (Age group: 14 vs. 19 months) x 2 (Trial type: Same vs. Switch) mixed design ANOVA. There was no main effect of age, $F < 1$, or trial type, $F(1,37) = 2.00$, $p = .165$, $\eta_p^2 = .051$. There was a significant interaction of age and trial type $F(1, 37) = 8.36$, $p = .006$, $\eta_p^2 = .184$. Paired samples t tests revealed that 14-month-olds looked significantly longer on Switch test trials than Same trials, $t(18) = 2.77$, $p = .013$, $d_z = .64$, indicating that they

learned the tone contour labels and detected when the original label-object pairings were violated (see Figure 3). Conversely, 19-month-olds did not differentiate Same versus Switch trials, $t(19) = -1.61$, $p = .260$, $d_z = -.36$, and thus displayed no evidence of learning the label-object pairings. The appendix reports the complete looking time means for all experiments (reported with and without outliers).

The findings of Experiment 1 suggest that 14-month-olds are more open to learning nonspeech labels than 19-month-olds. The results are consistent with prior evidence that older infants show greater constraints on the properties they accept as object labels than younger infants (e.g., Namy & Waxman, 1998). Even though younger infants are generally more flexible than older infants, their learning of nonspeech labels in the present task is somewhat surprising, given that infants around this age have exhibited native language constraints on label learning (MacKenzie et al., 2012; May & Werker, 2014). Although in rich interactive tasks, infants as old as 18 months have demonstrated learning of non-speech acoustic labels (e.g., beeps, whistles) (Campbell & Namy, 2003; Namy, 2001; Woodward & Hoyne, 1999), this had not been demonstrated in a task using looking measures, such as the Switch task.

One possible explanation for our findings is that the younger infants may be particularly sensitive to the acoustic salience of the contrast used in the Experiment 1. Rising versus falling tones are highly distinctive as they begin at very different fundamental frequencies and exhibit very distinct F0 trajectories that unfold over hundreds of milliseconds. Rising versus falling tones also appear to be more readily discriminated than some other tone contrasts (e.g., So & Best, 2010). Thus, the acoustic distinctiveness of the tones may have promoted 14-month-olds' mapping (for a more thorough examination of the role of acoustic salience and lexical tone learning see Hay, Cannistraci, & Zhao, Under review). The idea that acoustic salience may support learning is not new. Indeed, 12-month-olds can map two words that differ only in lexical stress (Curtin, 2009), at 14 months vowel-based minimal pairs that are more distinctive are more readily mapped than those that are less distinctive (Curtin, Fennell, & Escudero, 2009), and 14-month-olds successfully map consonant-based pairs in which the formant transition unfolds over a longer duration (i.e., liquid sonorants; *reet* vs. *leet*) but not a shorter duration (Archer & Curtin, 2018). Thus, acoustic salience may be a component of the label's properties that affects learnability. By 19 months, other factors, including expectations about acceptable native language word forms, may override acoustic salience.

Another possibility is that the linguistic nature of the nonspeech labels' prosodic contours may have played a role in 14-month-olds' label learning. As previously mentioned, infants this age attend to pitch contour in new spoken words (Hay et al., 2015). Thus, they may have relied on a language-like property to promote learning of nonspeech stimuli. In Experiment 2, we explored the limits of 14-month-olds' label learning by presenting them with nonspeech labels that lack language-like properties.

Experiment 2

To test 14-month-olds' learning of nonspeech labels that are divorced from linguistic properties, the labels in Experiment 2 consisted of pairs of synthesized tones spliced together. They mimicked the general trajectory of the nonspeech tone contour labels in Experiment 1 (rising vs. falling) but lacked the smooth, naturalistic transitions in pitch. Given prior evidence of constraints on early label learning, we predicted that 14-month-olds would reject the nonspeech labels.

Method

Participants—Nineteen 14-month-olds participated (9 females; $M = 14.49$ months, $SD = 0.31$, range = 14.0 – 15.0). Infants came from the population described in Experiment 1 and all were monolingual English learners. One additional infant was identified as an outlier (looking time difference score greater than 2 SDs from the M) and was excluded from final analyses. Three additional infants were excluded due to fussiness or crying.

Stimuli—The objects used during habituation and test trials were identical to those described in Experiment 1, but the labels differed. As in Experiment 1, one label exhibited a rising pitch, and the other a falling pitch. However, instead of a continuous pitch contour, each label consisted of two concatenated synthesized tones. To create the dual tone label stimuli, we analyzed one rising and one falling label token from the original speech stimuli to assess the mean frequency of the high and low pitch segments of the vowel (using Praat audio processing software; Boersma & Weenink, 2012). Tones were created with the same frequency as these high and low pitch segments. These tones were then concatenated to produce one rising (low pitch to high pitch; 225 to 281 Hz) and one falling (high pitch to low pitch; 341 to 243 Hz) dual tone label of approximately the same duration as the nonspeech tone contour stimuli in Experiment 1 (rising = 714 ms; falling = 703 ms). During each trial, the label was repeated with 750 ms of silence between presentations.

Procedure—The procedure was identical to Experiment 1, with the exception that dual tone labels were used in place of the tone contour labels.

Results and discussion

Infants habituated in a mean of 11.42 trials ($SD = 6.00$), accumulating 119.4 s ($SD = 65.4$) of exposure.

To examine infants' learning, we performed a paired-samples t test, which revealed that infants did not differ in looking time to Same versus Switch test trials, $t(18) = .933$, $p = .363$, $d_z = .222$. As illustrated in Figure 3, there is no evidence that infants learned the dual tone labels.

In Experiment 1, we established that 19-month-olds displayed no evidence of learning nonspeech labels that have language-like pitch contours. Fourteen-month-olds successfully paired the same sounds with novel objects. However, 14-month-olds do not display unlimited flexibility in label learning. They failed to learn dual tone labels that included rising versus falling patterns but lacked language-like pitch contours. The infants rejected

highly artificial tone labels. Thus, across Experiments 1 and 2, we demonstrated a difference in openness to learning of nonspeech labels across development from 14 to 19 months of age, as well as a boundary for openness in early label learning based on the acoustic characteristics of the labels. In Experiment 3, we tested the range of infants' flexibility when referential context is available.

Experiment 3

Past work has found that providing infants with referential context broadens the range of speech sounds infants accept as labels for objects (e.g., MacKenzie et al., 2014; May & Werker, 2014; Vukatana et al., 2016). Experiment 3 incorporated referential support with the nonspeech label-learning task from Experiments 1 and 2. It was designed to examine whether the range of sounds infants accept as labels for objects is malleable, or whether infants reject these nonspeech labels regardless of context.

To assess the boundaries of acceptable word forms, we tested 14- and 19-month-olds on labels that each age group had previously failed to learn. Nineteen-month-olds heard the tone contour stimuli from Experiment 1 and 14-month-olds heard the dual tone stimuli from Experiment 2. In Experiment 3, prior to habituation infants were exposed to several familiar object labeling trials to provide referential context for the label learning task. By referential context, we are not proposing that the task provides rich social meaning or invokes theory of mind. Rather, we propose that seeing familiar objects and hearing familiar labels cues infants that this potentially ambiguous task is a context in which one hears names for objects. This cue then primes the infants to form new mappings between names and objects.

Method

Participants—Twenty-one 14-month-olds (10 females; M = 14.40 months, SD = .355, range = 13.63 – 14.87) and twenty 19-month-olds (11 females; M = 19.54 months, SD = .29, range = 19.07 – 20.0) participated in Experiment 3. Infants came from the population described in Experiment 1, and primarily heard English, though nine infants had exposure to a second language. Eight infants heard up to 4% of their total language exposure in a second language: Spanish (7); French (1). One infant heard 15% German; the pattern of results is unchanged with this infant excluded. No infants were exposed to tonal languages. Two additional 14-month-olds and one additional 19-month-old were identified as outliers and excluded from final analyses. Sixteen additional infants were excluded due to fussiness or crying (14 months: 7; 19 months: 5) and excessive movement (19 months: 4).

Stimuli—The habituation and test stimuli were identical to Experiment 1 for 19-month-olds and Experiment 2 for 14-month-olds. Prior to habituation, infants viewed four familiar object label trials (kitty, doggy, baby, shoe) to provide referential context (Fennell & Waxman, 2010; May & Werker, 2014). The items are reported to be among the first words infants learn in English according to parental report (Fenson et al., 2007). During familiar object trials, an object moved vertically back and forth across a black background at approximately infant eye level while repetitions of its label played in an infant-directed manner, with 750 ms of silence between each repetition.

Procedure—The habituation and test procedures were identical to Experiment 1. Prior to habituation, infants viewed four familiar object labeling trials. Familiar object trials ended when the infant looked away from the screen for more than 1 s or after 10 s had elapsed. The familiar trials were presented in four counterbalanced orders.

Results and discussion

Infants accumulated a mean of 35.91 s (*SD* = 5.87) of exposure to the four familiar objects (*M* = 8.98 s, *SD* = 1.47 s per object), with no difference between age groups (14 months: *M* = 34.91 s, *SD* = 6.75; 19 months: 36.95 s, *SD* = 4.74).

The 14-month-olds met the habituation criterion in a mean of 114.8 s (*SD* = 69.2), across 13.2 trials (*SD* = 7.41). The 19-month-olds met the habituation criterion in a mean of 109.7 s (*SD* = 62.4) across 10.0 (*SD* = 4.68) trials. There was no significant difference between the ages in number of seconds (*p* = .805) or trials to habituate (*p* = .104).

We performed a 2 (Trial type: Same vs. Switch) x 2 (Age: 14 vs. 19 months) mixed design ANOVA of infants' looking times. There was a marginal main effect of trial type, $F(1, 39) = 2.78$, $p = .104$, $\eta_p^2 = .066$; infants tended to look longer on Switch trials than on Same trials. There was no main effect of age (*p* = .886) and no age x trial type interaction (*p* = .171).

Given our hypotheses, we performed planned comparisons to examine the 14- and 19-month-olds separately. As shown in Figure 4, only the 14-month-olds reliably differentiated the Same and Switch test trials, $t(20) = 2.20$, $p = .039$, $d_z = 0.48$. The 19-month-olds showed no significant difference, $t(19) = 0.19$, $p = .852$, $d_z = 0.04$. These findings suggest that with referential context, 14-month-olds learned nonspeech object labels that they had previously failed to learn. The dual tone labels were highly artificial synthesized sounds, so it is remarkable that infants learned them at an age that infants already reject spoken labels that do not follow their native language structure (when they occur without referential support; e.g., MacKenzie et al., 2012; May & Werker, 2014). In contrast, 19-month-olds' performance learning nonspeech labels was unchanged when presented with referential context or without it. They displayed no evidence of learning labels that contained salient language-like properties, even in the presence of referential context. The younger infants displayed greater malleability than the older infants in their acceptance of the (otherwise poor) label candidates.

Experiment 4

The results of Experiment 3 suggest developmental differences in label learning, but it is necessary to examine an alternative hypothesis for 19-month-olds' failure to acquire the nonspeech labels in Experiments 1 and 3. Infants may reject the labels because of acquired constraints on learning, as we have proposed, or infants may be unable to perceive the difference between the nonspeech pitch contours. If 19-month-olds cannot detect the contour contrast, this would hinder their ability to use the sounds as separate labels for objects. Experiment 4 assessed this possibility by presenting infants with a perceptual discrimination task. If infants can discriminate between the two nonspeech tone contour labels, this would

suggest that their failures in Experiments 1 and 3 were not solely due to difficulty differentiating the rising and falling contours.

Method

Participants—Sixteen 19-month-old infants (8 females) participated in Experiment 4 (M = 19.66 months, SD = .22, range = 19.35 – 20.04). Infants were born full term and did not have any reported vision or hearing problems. All infants were tested in eastern Tennessee and heard only English. Eight additional infants were excluded due to fussiness or inattentiveness (5) and equipment error (3).

Stimuli—The auditory stimuli were identical to those described in Experiment 1. In the perceptual discrimination task, the labels were not paired with objects. Instead, the screen displayed the same multicolored checkerboard pattern during each trial.

Procedure—Infants first participated in habituation trials, during which they heard repetitions of either rising or falling tone contours presented in isolation with 750 ms of silence between repetitions. One half the infants were habituated to the rising contour and one half were habituated to the falling contour. While the auditory stimuli were playing, infants viewed a central fixation checkerboard pattern. The habituation criterion was identical to Experiment 1. After habituation, there were two test trials. In the Same trial, infants heard the same tone contour as habituation while viewing the checkerboard, and during the Switch trial infants heard the opposite tone contour. One half of the infants heard the Same trial first and one half heard the Switch trial first. If infants perceived the difference between the two pitch contours, they should dishabituate to the novel pitch contour during the Switch trial.

Results and discussion

The infants reached the habituation criterion in an average 81.16 s (SD = 47.77) and 8.06 trials (SD = 2.38). They looked significantly longer on the Switch trial (M = 9.72 s, SD = 5.38) than on the Same trial (M = 5.85 s, SD = 5.14), paired samples t(15) = 2.53, p = .023, d_z = .63. This finding indicates that 19-month-olds can perceive the difference between the rising and falling tone contour labels. However, the findings from Experiments 1 and 3 indicate that they do not readily treat these forms as labels.

General discussion

In a series of experiments, we examined developmental changes in infants' learning of nonspeech object labels presented with and without referential context. We found evidence of the development of intersecting constraints. First, the results of Experiment 1 indicate that older infants are more restricted in the acoustic forms that they accept as object labels than younger infants; 14-month-olds accepted rising and falling nonspeech tone contours as object labels, but 19-month-olds did not. The younger infants displayed constraints on learning in Experiment 2, rejecting highly artificial dual tone labels. Second, the results of Experiment 3 indicate that older infants are more conservative in how referential context affects label learning. Fourteen-month-olds learned dual tone labels after exposure to

referential support, but even with referential context, 19-month-olds did not map nonspeech tones with natural pitch contours to objects. Across the experiments, we have demonstrated interpretative narrowing of the forms that infants accept as object labels, but also that interpretive narrowing is sensitive to the context in which object labels are presented. The effects of developmental level, label features, and context are intimately linked.

The current findings are consistent with prior evidence of linguistic constraints on label learning in similar tasks measuring infants' looking responses. Fourteen- and 20-month-olds appear to reject labels containing non-native click phonemes (May & Werker, 2014). However, when infants were presented with referential context similar to the context presented in Experiment 3, the younger infants accepted the labels, but older infants did not (May & Werker, 2014; see also Singh, 2017, for comparisons across bilinguals and monolinguals in a related task). In experiments using native language phonemes in novel combinations, 12-month-olds (MacKenzie et al., 2014) and 16-month-olds accepted phonotactically illegal labels after experiencing referential context, but 20-month-olds rejected the labels even with the supportive context (Vukatana et al., 2016). We have extended the investigation of label learning in the Switch task to demonstrate that early in word learning, referential context can promote learning of labels that would otherwise be rejected, even for nonspeech labels.

Our findings also provide a bridge across lines of research investigating the types of symbols that infants accept as labels. The early research by Namy and colleagues (Campbell & Namy, 2003; Namy et al., 2004; Namy & Waxman, 1998) and Woodward and Hoyne (1999) used highly interactive tasks in which the experimenter engaged in a social interaction with the infant, used episodes of joint attention to present spoken words and nonspeech labels, and produced labels in familiar labeling phrases. These studies indicated that infants shift in the forms of labels they learn readily sometime after 18 months of age. Recent experiments using the Switch task have revealed earlier narrowing in infants' acceptance of spoken label forms, occurring by 12 to 14 months (MacKenzie et al., 2014; May & Werker, 2014). However, the range of infants' flexibility was not yet clear. Here, we tested how infants learn nonspeech labels (previously tested in interactive tasks) in the Switch task (previously used with spoken labels). In the case of nonspeech labels, our findings suggest that the beginning of narrowing occurs as early as 14 months, which is earlier than what was observed in interactive tasks. Together, the rich social referential paradigm and the Switch task with referential context illustrate that referential support (even a small amount) can substantially alter the kinds of labels that infants learn. Simple exposure to familiar words is sufficient to push young infants to treat nonspeech tones like object names.

A question that arises from examining the effects of context on label learning is what is the function of referential context? One possibility is that it could promote infants' attention to relevant linguistic information, allowing infants to display more sophisticated processing than they are able to exhibit without support. The initial experiments by Fennell and Waxman (2010) suggested that this could be the case. Fourteen-month-olds typically fail to learn object label pairs that differ by a single native-language phoneme in tasks like the Switch task (Stager & Werker, 1997). However, when Fennell and Waxman provided context by presenting familiar objects and their labels or introducing the novel labels in familiar

labeling phrases (e.g., "Look at the *bin*"), infants displayed a previously obscured ability to detect phoneme distinctions in new words. However, in recent applications of the method and in comparisons across research methods, it appears that referential context can also promote flexibility in label learning that does not necessarily look sophisticated; rather, it encourages infants to attend to information that is not relevant in their native language(s). Contextual information about labeling events can counter infants' native language-specific processing, at least in the moment. Here, we found that 14-month-olds rejected dual tone labels, unless labeling context information was activated. Infants also disregard phonotactic constraints and native language phoneme constraints when learning labels after referential context (MacKenzie et al., 2014; May & Werker, 2014).

The results across these studies suggest that instead of consistently helping infants process speech in a more sophisticated way, referential context encourages a broad acceptance of label forms. It may activate prior experiences appropriately linking names to referents in similar situations. The process generalizes to non-native phonemes, illegal phoneme combinations, or even nonspeech labels. Referential context may sometimes even act as a cue to infants that these forms should be considered part of the native language, much like experience with non-native speech can shift infants' willingness to accept non-native labels (San Juan, Lin, MacKenzie, Curtin, & Graham, Under review). Nevertheless, the force of referential context diminishes across development. There are two likely candidates for this change. First, infants develop stronger expectations about the acoustic forms that labels take, becoming more reluctant to learn labels that violate these expectations. Their native language knowledge becomes more firmly entrenched as they accrue exposure and vocabulary items, inhibiting learning of non-native word forms. Native language knowledge also eases acquisition of new words that fit with prior experience as infants build robust phoneme representations that can be combined flexibly in new words and as they establish stored representations of common sound sequences. Second, infants develop stronger expectations about labeling contexts. They accumulate experiences in which referential context cues learning of verbal labels with particular phonemic and phonotactic structure. Thus, the influence of referential context for atypical symbols (relative to infants' prior experiences) may diminish. The interaction of developmental level, label properties, and labeling context that we have described for nonspeech labels builds from Werker and Curtin (2005) and Curtin et al.'s (2011) PRIMIR framework for understanding infant speech perception and word learning.

The ideas presented here about the development of word learning constraints come from research across different methodologies, testing infants in different populations at different ages, and using different label types. Future research will be needed to clarify the nature of the interaction of the factors of developmental level, label characteristics, and context (Werker & Curtin, 2005). These studies will require a consistent methodology, presenting labels with varying levels of referential support, multiple age groups, and a range of label types (common sound sequences, rare sound sequences, illegal sound sequences, non-native phonemes, salient contrasts, subtle contrasts, nonspeech stimuli with language-like properties, nonspeech stimuli without language-like properties). With this approach, it will be possible to trace the development of interpretive narrowing for words that vary in linguistic properties and how narrowing is shaped by the ways that labels are presented. For

example, we predict that older infants will be open to learning labels that are unusual, but consistent with native language properties (e.g., containing rare phoneme combinations) when the labels are presented with referential context. There is prior evidence that 19-month-olds do not learn such labels in a context-free task (Graf Estes & Bowen, 2013). In another example, this approach is likely to reveal graded effects of referential context. Infants around 18 months can learn nonspeech labels in a social interaction (Namy, 2001), but the referential context provided in Experiment 3 was insufficient. However, if richer support is provided, we may also see an extension of openness in nonspeech label learning in a task using looking measures.

Future research will also be necessary to explore the effects of different types of nonlinguistic labels. It is possible that the effects we demonstrated with rising and falling nonspeech tone contours and dual tones do not broadly generalize to other types of nonspeech labels. For example, in a simplified Switch task in which one novel object was labeled following referential training with familiar objects, Singh (2017) found that monolingual and bilingual 19-month-olds did not detect the change when a clap sound label switched to a snap sound. This suggests a lack of openness to nonspeech labels, which contrasts with our findings, but it is not yet possible to determine if the effect is related to methodological differences or specific to the nature of the labels.

In conclusion, this series of experiments demonstrated how word learning is affected by the interacting forces of development, label form, and learning context. Consistent with experimental tests of spoken label learning (e.g., May & Werker, 2014) and models of speech perception—word learning links (i.e., PRIMIR, Werker & Curtin, 2005), infants' learning of nonspeech labels displays the interconnected influences of these factors; one cannot accurately understand infants' constraints on label forms without considering developmental level and the requirements of the current learning task. Our findings add to a growing literature indicating that as infants begin language acquisition, they are open to many possible label forms. With experience, infants privilege label forms and labeling contexts that are characteristic of their environments, and therefore are most likely to support further learning.

Acknowledgments

Appendix

Means (and Standard Deviations) of Looking Times (in sec) by Experiment and by Age Group

| Experiment	Age	Same trials M (SD)	Switch trials M (SD)	N
Final sample excluding outliers				
Exp. 1: Pitch contours	14 months	6.13 (3.17)	8.09 (3.78)	19
	19 months	7.67 (3.62)	7.00 (4.13)	20
Exp. 2: Dual tones	14 months	7.04 (3.70)	6.52 (3.01)	19
Exp. 3: Context with dual tones	14 months	5.93 (3.18)	7.25 (4.24)	21
Exp. 3: Context with pitch contours	19 months	6.67 (3.23)	6.79 (3.00)	20
Sample including outliers				
Exp. 1: Pitch contours	14 months	6.74 (3.60)	7.71 (3.83)	21
	19 months	7.72 (3.54)	7.36 (4.35)	21
Exp. 2: Dual tones	14 months	7.05 (3.60)	6.96 (3.52)	20
Exp. 3: Context with dual tones	14 months	6.67 (3.91)	7.17 (4.09)	23
Exp. 3: Context with pitch contours	19 months	6.90 (3.25)	7.00 (3.41)	22

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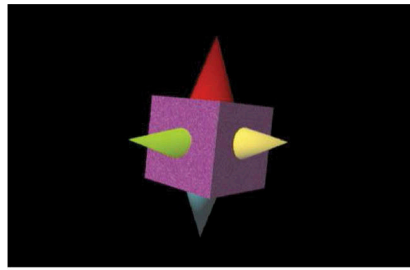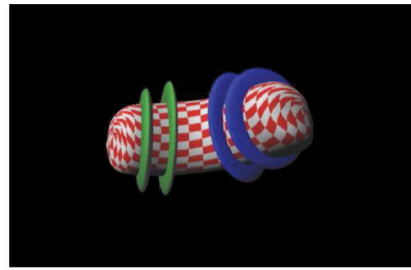
Object 1   Object 2

Figure 1.
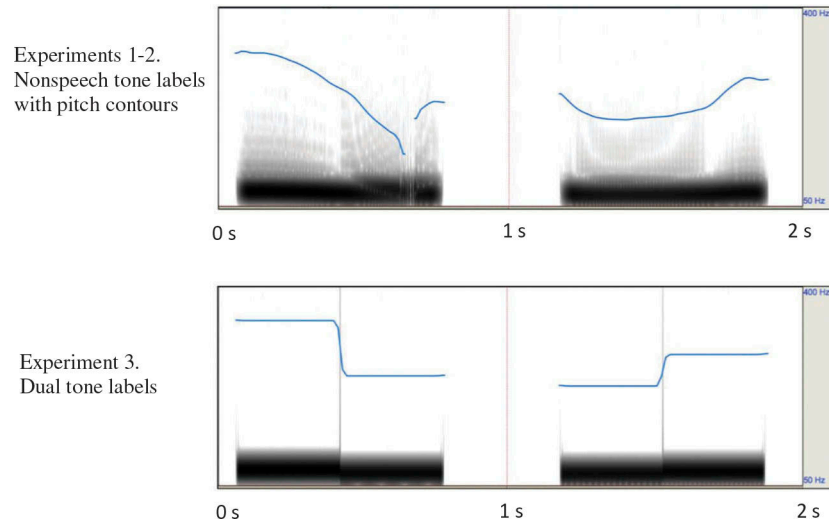Objects used in label-object association task. Label-object pairings were counterbalanced.

Figure 2.
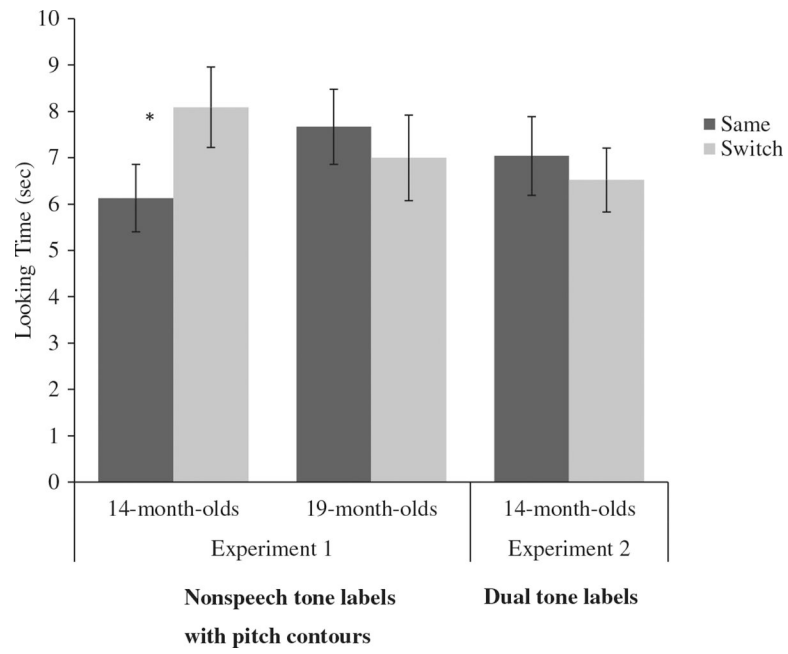Spectrogram and pitch contours (blue lines) for nonspeech labels.

Figure 3.
Experiment 1–2 mean looking time (in sec) to Same and Switch test trials. Error bars represent Standard Errors.
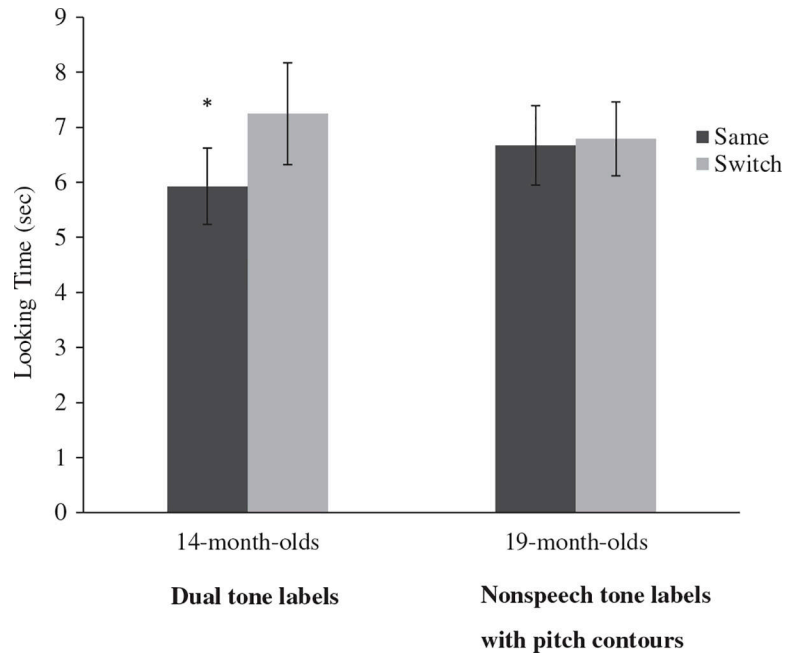
* $p < .05$.

Figure 4.
Experiment 3 mean looking time (in sec) to Same and Switch test trials. Error bars represent Standard Errors.

* *p* < .05.