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From Flexibility to Constraint: The Contrastive Use of Lexical Tone in Early Word Learning

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Infants must develop both flexibility and constraint in their interpretation of acceptable word forms. The current experiments examined the development of infants' lexical interpretation of non-native variations in pitch contour. Fourteen-, 17-, and 19-month-olds (Experiments 1 and 2, $N = 72$) heard labels for two novel objects; labels contained the same syllable produced with distinct pitch contours (Mandarin lexical tones). The youngest infants learned the label–object mappings, but the older groups did not, despite being able to discriminate pitch differences in an object-free task (Experiment 3, $N = 14$). Results indicate that 14-month-olds remain flexible regarding what sounds make meaningful distinctions between words. By 17–19 months, experience with a nontonal native language constrains infants' interpretation of lexical tone.

A fundamental challenge facing novice language learners is to determine which sounds in the ambient environment carry meaning. The complexity of this problem is lost on most adult language users, who effortlessly reject a wide range of nonspeech sounds as labels for objects. For example, the "vrrmm" of a vacuum cleaner, the "achoo" of a sneeze, and the "tsk tsk" in response to a naughty act would not be considered potential lexical items. Infants, on the other hand, must learn to identify which sounds in their environments are lexically relevant and which sounds are not and thus should be rejected as potential labels.

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A great deal of research has suggested that infants start out open-minded about what makes an acceptable word form. They then display appropriate, language-specific narrowing regarding the kinds of units they are willing to treat as potential object labels. For example, early word learners, around 13–17 months of age, readily map words (e.g., *toma*) and nonspeech sounds (e.g., a squeak, Woodward & Hoyne, 1999; a two-tone beep, Namy, 2001) to novel objects when they are presented during interactive labeling events. They also associate nonverbal mouth noises (e.g., *psst*; Hirsh-Pasek, Golinkoff, & Hollich, 2000) as well as gestures and pictograms (Namy, 2001) with objects. Early flexibility in what counts as a word may prove to be adaptive for subsequent word learning, as infants do not know a priori which sounds and symbols in their environment are lexically relevant.

As infants get older, they amass knowledge of the sound repertoire of their native language, and demonstrate increasing sensitivity to native word forms. For example, older infants (around 20 months and above) often fail to map nonspeech symbols to objects (Namy & Waxman, 1998; Woodward & Hoyne, 1999). This change in what infants' consider to be acceptable word forms is appropriate

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and useful, as these variations are not used contrastively in the infants' native language.

The narrative about narrowing in early word learning is quite complex, however. In contrast to the literature reviewed above, recent research suggests that sophisticated constraints on what infants count as a word may emerge very early in development. MacKenzie, Graham, and Curtin (2011) demonstrated that 12-month-olds privilege words as object labels over other vocally produced nonlexical sounds in nonsocial associative learning tasks (see MacKenzie et al., 2011, for a discussion of methodological considerations). Infants successfully learned label–object mappings when the labels were two English nonsense consonant-vowel-consonant (CVC) words (*fep* and *wug*), but not when they were consonant- or vowel-based communicative sounds (*mmm* and *shhh; oooh* and *aaah*), or noncommunicative sounds (/l/ and /ʒ/). MacKenzie, Curtin, and Graham (2012) also demonstrated that 12-month-olds are constrained by phonotactic regularities of their native language. Infants mapped non-native words that were phonotactically legal in English (e.g., *mido* and *hashi*) to novel objects, but not words that violated English phonotactic regularities (e.g., *ptak* and *svet*, which contain word onset consonant clusters that never occur in English). These studies suggest that even the youngest word learners have some basic understanding of acceptable word forms.

Languages use many ways to create acceptable word forms and to mark distinctions between words. For example, speakers can change many word meanings by simply altering a single segmental element (e.g., ball → tall; bat → bit). Thus, one might expect infants to be particularly sensitive to this type of lexically contrastive distinction early on. Numerous studies, however, have demonstrated that 14-month-olds fail to map minimal pair nonsense words (e.g., /bI/-/dI/; /pIn/-/bIn/; /pIn/-/dIn) to novel objects (e.g., Pater, Stager, & Werker, 2004; Stager & Werker, 1997), even though both place of articulation (e.g., /b/-/d/) and voicing (e.g., /b/-/p/) distinctions are lexically contrastive in English, and infants can readily discriminate them when no objects are present (Stager & Werker, 1997). A number of theories have been proposed to account for 14-month-olds' performance in these minimal pair label–object mapping tasks, including capacity limitations (e.g., Fennell, 2012; see also Werker & Curtin, 2005; Yoshida, Fennell, Swingley, & Werker, 2009), lack of social/referential support (e.g., Fennell & Waxman, 2010), and insufficiently robust phonological representations (Apfelbaum & McMurray, 2011; Galle, Apfelbaum, & McMurray, in press; Rost & McMurray, 2009, 2010). Nevertheless, even without referential support, by around 17 months, infants succeed in learning label pairs that differ by a single phoneme (e.g., Werker, Fennell, Corcoran, & Stager, 2002). Thus, it appears that language experience helps infants appropriately interpret phoneme distinctions.

In addition to segmental contrasts, many languages use lexical tones or pitch contours, which are suprasegmental features, to form lexical contrasts. Languages that use pitch contour contrastively are called tone languages (e.g., Mandarin Chinese, Cantonese, Thai). They comprise 60%–70% of the world's languages (Yip, 2002), and are spoken by over 50% of the world's population (Fromkin, 1978). Lexical tones typically reflect variations in the level or contour of the fundamental frequency (F0; pitch) within a single syllable (e.g., Burnham & Mattock, 2007; Liu & Samuel, 2004), as well as additional acoustic correlates of physical duration, F2, voice quality, and amplitude. Figure 1 illustrates lexical tones that occur in Mandarin, the most widely spoken tone language. The four citation tones in Mandarin can be categorized as high level (T1), high rising (T2), low dipping (T3), and high falling (T4). For instance, /ma/ can mean "mother," "hemp," "horse," and "to scold" when carrying T1, T2, T3, and T4, respectively. Precisely how languages instantiate lexical tone varies from one language to the next, but in most tone languages, lexical tone is crucial for determining the meaning of a word.

In nontone languages, like English, pitch also varies in meaningful ways. In English, pitch is

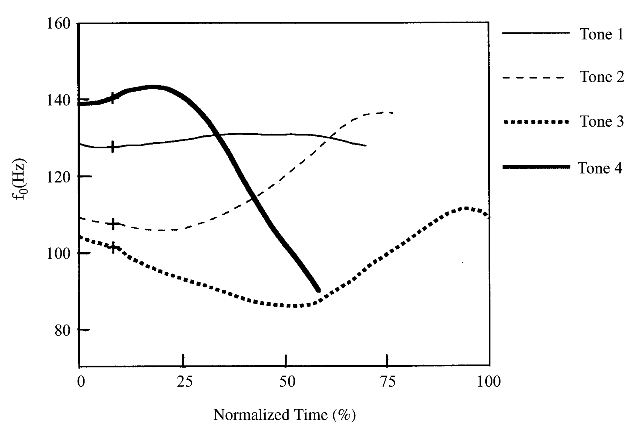

Figure 1. Mean F0 contour of four Mandarin tones in the /ma/ monosyllable produced in isolation. The time course is normalized, with all tones plotted with their average duration proportional to the average duration of T3 (Xu, 1997, p. 67, reprinted with permission).

commonly used to communicate intonational and emotional meaning (e.g., Bolinger, 1989; Hirschberg & Ward, 1992; Pierrehumbert, 1980; Ward & Hirschberg, 1985), highlight aspects of grammatical structure (e.g., Gussenhoven, 2004) and lexical stress (e.g., Fry, 1958), and differentiate talker identity, talker gender, and talker register (e.g., infant- vs. adult-directed speech; Fernald, 1992). Although pitch conveys information and is a salient acoustic characteristic of the speech signal in English, it is not used contrastively for word meaning. Still, young English-learning infants are highly familiar with pitch variation in their speech input and show sensitivity to many of these systematic pitch variations (e.g., Fernald, 1989, 1992; Fernald & Kuhl, 1987; Katz, Cohn, & Moore, 1996; Moore, Spence, & Katz, 1997). Moreover, the presence of lexically irrelevant pitch variation can actually help infants to detect lexically relevant phonemic differences (such as voice-onset-time) in minimal pair word learning tasks (Galle et al., in press; Rost & McMurray, 2009, 2010).

Recent work by Quam and Swingley (2010) suggests that English-learning children and adults are unable to exploit contrastive pitch contours when learning new words, even when pitch contour is the only relevant lexical cue. Adults and 2.5-year-olds were taught a novel object–label pairing, where the label (*deebo*) was produced with a consistent and salient pitch contour. When tested, both adults and toddlers failed to notice a salient non-phonemic change in the word's pitch contour (e.g., *deebo* with rising then falling contour was changed to *deebo* with level then falling contour, or vice versa). In contrast, they noticed a phonemic change in the word's vowel (e.g., *deebo* to *dahbo*). Quam and Swingley suggested that children may not have interpreted salient pitch contour changes as lexical changes because by 2.5 years of age children have accumulated a great deal of evidence indicating that pitch contour variation is not lexically contrastive in English.

Thus, by 2.5 years of age, English-learning children show a constrained interpretation of pitch contour, namely, that different pitch contours do not mark distinct word meanings. How much English-language experience is necessary for this constraint to develop? Are very young word learners, who have less experience with the functions of pitch variation, more flexible in their interpretation of distinctive pitch contours than more experienced word learners?

In the current set of experiments, we investigated the developmental trajectory of infants' flexibility in early word learning by assessing infants' willingness to accept lexical tones as lexically contrastive. Specifically, the focus of the current set of experiments was infants' ability to map labels that differ only in lexical tone to novel objects. As mentioned previously, lexical tones are used in tone languages to minimally contrast words and typically reflect pitch variations within a single syllable. Lexical tones provide an informative test case for asking about infants' flexibility in determining which sound differences point to meaningful distinctions between words. While English-learning infants experience extensive pitch variations in their speech input, a significant amount of language experience may be necessary before they can assign pitch variations to their appropriate (nonlexical) linguistic functions (see also Dietrich, Swingley, & Werker, 2007). In addition, the pitch contour variations in lexical tones are particularly acoustically salient compared to phonemic differences between many consonants. Thus, early in word learning, as English-learning infants are trying to discover which acoustic properties of sounds in the environment make lexical contrasts, the salience of pitch may prove more useful than later on, when infants have access to numerous other cues (e.g., voice-onset time) pointing out lexical contrasts. Nevertheless, pitch contours represent a cue that English-learning infants must learn to ignore when interpreting the meanings of words, as they are largely lexically irrelevant in English.

This series of experiments investigated whether very young word learners have a constrained interpretation of pitch contours, or whether they are open-minded about the lexical relevance of pitch contours. As learners gather experience about their nontonal native language, pitch contour may become a less lexically relevant cue. To begin addressing these issues, in Experiment 1 we examined flexibility in early word learning by testing whether 14-month-old infants can map meanings to labels that contrast only in lexical tone. It would be adaptive for infants to remain flexible during the early stages of word learning, as they do not know a priori which language environment they will be brought up in. Thus, we predicted that young word learners should readily map labels that contrast in lexical tone to novel objects.

Experiment 1

In Experiment 1, we assessed flexibility in early word learning by testing whether 14-month-olds associate novel labels with novel objects when the labels differ only in pitch contour (/kʊ/ with rising contour vs. /kʊ/ with falling contour). We used a modified version of the Switch Paradigm, which is an associative learning task without contextual or referential support, to ensure that learning would not be carried solely by the social context of the testing situation (see MacKenzie et al., 2011, for a discussion of methodological considerations). We selected rising versus falling contours because previous research has suggested that across the 1st year, both tonal language- and nontonal language-learning infants maintain the ability to discriminate between rising versus falling pitch contours in a nonword learning context (Mattock & Burnham, 2006). Finally, we chose to test 14-month-old infants because previous research suggests that infants around this age show both flexibility in what counts as a word (Woodward & Hoyne, 1999) and constraint in what sounds they find meaningfully contrastive (MacKenzie et al., 2011; Mackenzie et al., 2012). In addition, it is one of the youngest ages at which infants successfully learn object–label mappings in experimental tasks (Curtin, 2009; but see MacKenzie et al., 2011; MacKenzie et al., 2012; Werker, Cohen, Lloyd, Casasola, & Stager, 1998). Although previous studies have suggested that 14-month-old infants have significant difficulty learning phonetically similar object labels (e.g., Stager & Werker, 1997; but see Yoshida et al., 2009), this is an age at which infants may be willing to interpret an acoustically salient but lexically irrelevant cue, such as differences in pitch contour, as meaningfully distinctive.

Method

Participants

Twenty-four 14-month-old (M_{age} = 14.2 months, range = 13.1–15.1; 12 female) monolingual English-learning infants from a mid-sized Midwestern American city participated in Experiment 1. All infants were born full-term, and had fewer than five prior ear infections, no history of hearing or vision impairments, and no exposure to any tone languages. Data from six additional infants were excluded from the analysis because of fussiness (four), experimenter error (one), or current ear infection (one).

Stimuli

To create the labels, an adult female native speaker of Mandarin Chinese produced the monosyllabic nonsense word /kʊ/ with a rising pitch contour and a falling pitch contour. Figure 2 shows the spectrograms for both rising and falling /kʊ/ overlaid with the fundamental frequency (F0). Tokens were selected to have similar overall durations (856 ms for rising /kʊ/ and 867 ms for falling /kʊ/). Rising /kʊ/ and falling /kʊ/ both started with 143 ms of aspiration followed voicing for the remainder of the syllable. During the voicing portion, rising /kʊ/ had a frequency of 245 Hz at the start of voicing, which fell to 200 Hz over the first 130 ms of voicing and then rose to 290 Hz over the remaining 570 ms of the syllable. Falling /kʊ/ had a frequency of 320 Hz at the onset of voicing, which fell to 190 Hz over the remainder of voiced portion of the syllable. Twelve tokens were repeated with an interstimulus interval (ISI) of 750 ms to create a 20 ms auditory stream.

As shown in Figure 3, the novel objects consisted of two distinct, multicolored, three-dimensional images. These objects have been used successfully in a number of other label–object mapping studies (e.g., Graf Estes, Evans, Alibali, & Saffran, 2007; Hay, Pelucchi, Graf Estes, & Saffran, 2011). Images were displayed in the center of the vertical axis of a 19-in. computer monitor and moved slowly back and forth in a linear path across the computer screen. The movement of the images continued uninterrupted at a rate of 6 cycles per second and was not synchronized with the presentation of the object labels.

Infants were randomly assigned to view Object A paired with rising /kʊ/ and Object B paired with falling /kʊ/, or vice versa. A level /la/ produced by the same Mandarin speaker served as a pretest stimulus and was paired with a third novel object.

Procedure

Infants were seated on a parent's lap in a sound-attenuated booth, approximately 1 m from a flat screen monitor. The stimuli were presented using Habit X 1.0 (Cohen, Atkinson, & Chaput, 2004). An observer viewed infants' responses on a monitor and indicated looking times by pressing a button on the computer running Habit. To avoid potential bias, the observer was blind to the identity of the materials being presented and the parent listened to masking music over headphones.

In order to familiarize infants with the task and to help avoid erroneous habituation as a result of very long looks on the first trial, infants were first presented with a pretest label and object pair: /la/ paired with a novel object. They were then habitu-

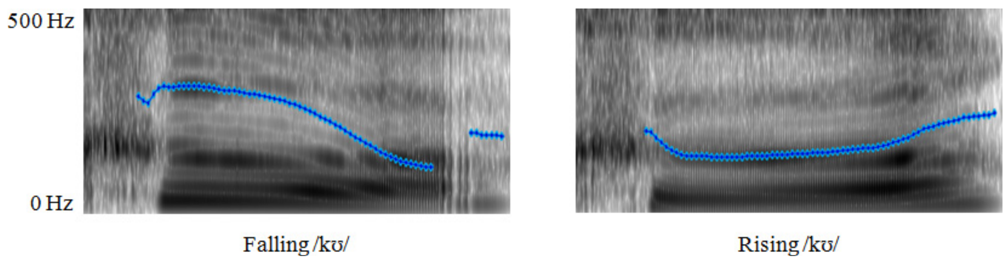

Figure 2. Spectrogram and pitch contour of falling /kʊ/ (left) and rising /kʊ/ (right).

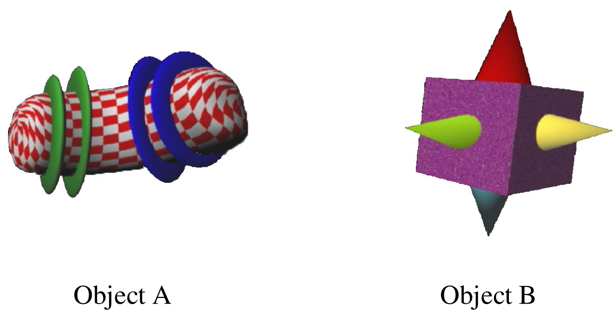

Figure 3. Objects used in label–object association task.

ated to the two lexical tone label–object pairs, presented one at a time, in random order. Each label–object combination played continuously while the infant looked at the screen, and terminated when the infant looked away for 1 s or after a maximum looking time of 20 s. After the infant looked away, a cartoon pinwheel played to recapture the infant's attention. Once the infant's attention was focused on the screen, the experimenter initiated the next trial. The habituation criterion was satisfied when looking time across three consecutive trials decreased to 50% of the average looking time across the first three trials.

Test trials began immediately after the infant habituated or reached the maximum cutoff of 25 trials. During same test trials, the infant viewed the label–object combinations that were presented during the habituation phase. During switch trials, the labels for the two objects were switched; for example, Object B occurred with Label A. There were four trials per block (two same and two switch trials) presented in four counterbalanced testing orders. Each block of test trials was presented twice for a total of eight test trials. Across the test trials, infants were presented with all possible combinations of labels and objects. The dependent variable was the looking time on same versus switch test trials. If infants learned the original label–object pairings, they should look longer during the switch test trials in which the pairings are violated (e.g., Werker et al., 1998).

Results and Discussion

All infants met the habituation criterion. Preliminary analyses revealed that there were no main effects or interactions involving infant sex, trial order, or test block; all subsequent analyses were performed collapsed across these variables. To examine whether infants successfully mapped rising /kʊ/ and falling /kʊ/ to different novel objects, we compared mean looking times on same and switch trials using a paired-samples t test (all t tests two-tailed; effect sizes reported for t tests are Cohen's d). The infants looked significantly longer to switch (M = 8.23 s, SD = 3.59) than to same (M = 6.63 s, SD = 2.95) trials, $t(23) = 2.11$, $p = .046$, $d = .43$, indicating that they learned the mapping between the labels and the objects (see Figure 4).

Our results suggest that although lexical tones are not used contrastively in English, 14-month-old infants are willing to map labels that differ only in pitch contour to novel objects. These findings are particularly surprising in light of the difficulty that 14-month-olds typically have mapping minimal pair words to novel objects when the words differ

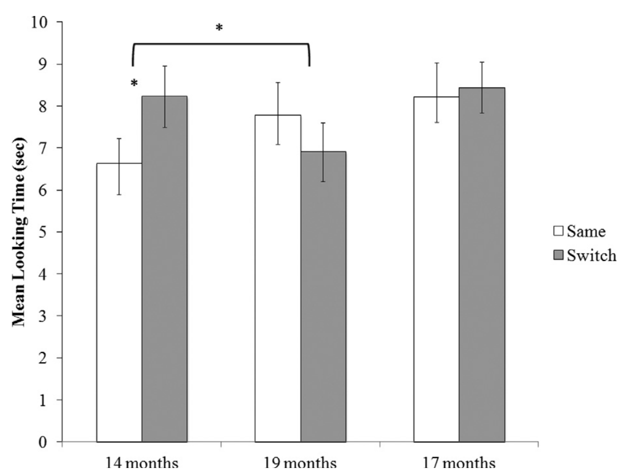

Figure 4. Results of Experiments 1 and 2. Average looking times (± 1 SE) on same and switch trials for 14-, 19-, and 17-month-olds.
*$p < .05$.

by a single phoneme (e.g., Stager & Werker, 1997), and given that our testing paradigm provided no referential support. The present results support the hypothesis that young learners are open to a variety of potential contrastive cues to word meaning.

One question that arises from the current study is why did our English-learning infants succeed in using lexical tones contrastively, when Quam and Swingley's (2010) participants failed to notice changes in pitch contour in newly learned words? There are a number of differences between the two studies that may account for the discrepancy. First, there were substantial methodological differences between the studies. By presenting falling /kʊ/ with one object and rising /kʊ/ with a second object, we provided infants with distributional information that may have facilitated the contrastive use of lexical tone. Support for this idea comes from recent work by Yeung and Werker (2009) who found that the presence of co-occurring contextual cues, such as consistently pairing objects with particular phoneme distributions, facilitates differentiation between phonetic categories. Thus, providing rising pitch contour with one object and falling pitch contour with a second object may have helped the infants differentiate between the two types of pitch contours, thereby facilitating the label–object associations. Participants in Quam and Swingley's experiments were not provided with the same type of distributional information. Instead, they were taught the label for a single object and thus did not receive information about the potential lexical relevance of pitch contour.

A second, and potentially more notable, difference between the two studies is the large age difference between the infants in our study (14 months) and Quam and Swingley's (2010) participants (adults and 2.5-year-olds). Between ages 1 and 2.5, children gain tremendous experience with the regularities of their native language. It is possible that across the 2nd year, infants learn to ignore or downweight variations in pitch contour while acquiring and interpreting words, because pitch contours are not lexically relevant in English. Consistent with this view, Dietrich et al. (2007) have demonstrated cross-linguistic differences in infants' willingness to treat vowel duration as meaningfully contrastive. Vowel duration, like pitch contour, is an acoustically salient phonetic property that is used to minimally distinguish words in some languages, like Dutch and Japanese, but not in other languages, like English and French. At 18 months of age, Dutch infants, but not English-learning infants readily map labels that differ minimally in vowel duration to novel objects.

It is thus unclear whether the results of Experiment 1 diverge from prior studies due to differences in the methodologies, or to differences in the age of the participants (and thus their degree of native language experience). To address these alternative hypotheses, Experiment 2 examined the developmental trajectory of infants' willingness to use lexical tone contrastively.

Experiment 2a

As infants gain language experience, they show increasing sensitivity to the structures and word forms of their native language. In Experiment 2a, we replicated Experiment 1 with 19-month-olds, who are typically more successful at mapping minimal pair labels to novel objects than their younger peers (e.g., Werker et al., 2002), and who are generally becoming quite skilled at word learning (Goldfield & Reznick, 1990; Werker et al., 1998). If the difference in performance between 14-month-old infants in Experiment 1 and the 2.5-year-olds examined by Quam and Swingley (2010) is due to methodological differences in the availability of distributional cues, then we would expect older infants to demonstrate contrastive mapping of pitch contours to novel objects in our task. However, if native language experience with a nontonal language is showing infants that pitch contours are not lexically relevant, then older infants should ignore the pitch contour of new words in our task. If this is the case, then 19-month-olds should fail to learn the tone minimal pairs under the same circumstances in which the 14-month-olds in Experiment 1 succeeded.

Method

Participants

Twenty-four 19-month-old (M_{age} = 19.75 months, range = 19.1–20.1; 13 female) monolingual English-learning infants from a mid-sized Midwestern American city participated in Experiment 2a. Exclusion criteria were identical to Experiment 1. Data from six additional infants were excluded from the analysis because of fussiness (four), parental interference (one), or looking for the total duration of the trial on more than five test trials (one).

Stimuli and Procedure

The stimuli and procedure were identical to those used in Experiment 1.

Results and Discussion

Twenty-three of the 24 infants met the habituation criteria within 25 trials. Data from all 24 infants were included in the analysis because excluding the infant who failed to habituate did not alter the results. Preliminary analyses revealed that there were no main effects or interactions involving infant sex, trial order, or test block; all subsequent analyses were performed collapsed across these variables. To examine whether 19-month-olds successfully mapped rising /kʊ/ and falling /kʊ/ to novel objects, we compared mean looking time on same and switch trials using a paired-samples *t* test. Looking times on switch ($M = 6.91$ s, $SD = 3.43$) and same ($M = 7.79$ s, $SD = 3.84$) trials did not differ significantly, $t(23) = 1.12$, $p = .274$, $d = .230$ (see Figure 4). These results suggest that 19-month-olds did not notice the labeling violation in the switch trials.

In order to verify that the performance of the 19-month-olds in Experiment 2 differed from the 14-month-olds tested in Experiment 1, we performed a 2 (age: 14 months vs. 19 months; between subjects) × 2 (trial type: same vs. switch; within subjects) mixed analysis of variance (ANOVA). There was no main effect of trial type, $F(1, 46) < 1$, *ns*, or age, $F(1, 46) < 1$, *ns*. Importantly, there was a significant Trial Type × Age interaction, $F(1, 46) = 5.162$, $p = .028$, $\eta_p^2 = .10$, supporting the contention that the two groups differed in their performance.

These results suggest that there is a developmental shift in infants' willingness to treat lexical tone contrastively. Fourteen-month-olds seem to be open to accepting labels that differ solely in pitch contour as different lexical items, despite the fact that pitch contour is not a lexically contrastive cue in their native language. However, by 19 months of age, infants appear to ignore pitch contour as a contrastive cue to word meaning. Results from Experiment 2a support the hypothesis that differences between our findings in Experiment 1 and those of Quam and Swingley (2010) are likely developmental in nature, rather than distributional in nature. Thus, between 14 and 19 months of age there appears to be a shift in infants' interpretation of the lexical relevance of pitch contour.

Infants' performance using lexical tone contrastively appears to be the inverse of their performance mapping consonantal minimal pairs to novel objects. We found that 14-month-olds succeeded in mapping tone-based minimal pairs, whereas infants of the same age typically fail in mapping phoneme-based minimal pairs (Pater et al., 2004; Stager & Werker, 1997). Similarly, we found that 19-month-olds failed to use tone-based minimal pairs, whereas 17- to 20-month-olds typically succeed in mapping phoneme-based minimal pairs (Werker et al., 2002). Improved mapping of phoneme-based minimal pairs likely results, at least partially, from increased attention to phonemic detail. Thus, 17 months may be a pivotal age at which infants become more sensitive to the acoustic properties of object labels. Experiment 2b tested this possibility.

Experiment 2b

In Experiment 2b, we replicated Experiments 1 and 2a with infants intermediate in age (17 months) in order to examine the possibility that developmental change in the contrastive use of lexical tone coincides with when infants begin to display greater attention to phonemic detail in newly learned words.

Method

Participants

Twenty-four 17-month-old ($M_{age} = 17.5$ months, range = 17.1–18.2 months; 13 female) monolingual English-learning infants from a mid-sized Southeastern American city participated in Experiment 2b. Exclusion criteria were identical to Experiments 1 and 2a. Data from nine additional infants were excluded from the analysis because of fussiness (four), experimenter error (three), or looking for the total trial duration on more than five test trials (two).

Stimuli and Procedure

The stimuli and procedure were identical to those used in Experiments 1 and 2a.

Results and Discussion

Twenty-one of the 24 infants met the habituation criteria within 25 trials. Data from all 24 infants were included in the analysis because excluding the 3 infants who failed to habituate did not alter the results. Preliminary analyses revealed no main effects or interactions involving infant sex, trial order, or test block; all subsequent analyses were performed collapsed across these variables. A paired-samples *t* test revealed that 17-month-olds showed no significant mean looking time difference in switch ($M = 8.44$ s, $SD = 2.96$) and same ($M = 8.22$ s, $SD = 3.98$) trials, $t(23) < 1$, $p = .74$, $d = .07$, indicating that they did not notice the labeling violation in the switch trials (see Figure 4).

In order to compare performance across age, we preformed a 3 (age: 14, 17, 19 months; between subjects) × 2 (trial type: same vs. switch; within subjects) mixed ANOVA. There was no main effect of trial type, $F(1, 69) < 1$, *ns*, or age, $F(1, 69) < 1$, *ns*. The Trial Type × Age interaction was only marginally significant, $F(1, 69) = 2.895$, $p = .062$, $\eta_p^2 = .077$. It appears that the 17-month-old infants' performance is intermediate between the 14-month-olds tested in Experiment 1, who succeeded in mapping lexical tones to novel objects and the 19-month-olds tested in Experiment 2a, who failed to make this mapping (for evidence of intermediate performance by 17-month-olds on phonemic-based minimal pair learning, see Werker et al., 2002).

The findings suggest that while infants begin to show increasing attention to phonemic detail during word learning tasks, they also become constrained in their use of lexical tone as a contrastive cue. As English-learning infants accrue knowledge that pitch contours are not relevant to word meaning, they ignore the pitch contours of words, much in the same way that they come to ignore the speaker's gender when interpreting word meaning (Houston & Jusczyk, 2000).

However, the same pattern of results could occur if infants lose the ability to discriminate rising versus falling pitch contours between 14 and 17–19 months of age. This would be consistent with the kind of perceptual narrowing that occurs for many non-native phoneme contrasts (e.g., Werker & Tees, 1984). Although perceptual narrowing is not a universally agreed upon theory of developmental speech perception (for examples of within-category discrimination, see Carney, Widin, & Viemeister, 1977; Massaro & Cohen, 1983; Toscano, McMurray, Dennhardt, & Luck, 2010; for examples of phoneme contrasts that are gained, not lost, see Eilers & Minifie, 1975; Eilers, Wilson, & Moore, 1977; Kuhl et al., 2006; Narayan, Werker, & Beddor, 2010; for various alternative theories of the development of speech perception, see Guenther & Gjaja, 1996; McMurray, Aslin, & Toscano, 2009; Vallabha, McClelland, Pons, Werker, & Amano, 2007), it has been widely documented that across the 1st year of life early broad sensitivity becomes fine-tuned as infants focus on the speech sound variants that are meaningfully distinct in their native language (e.g., Anderson, Morgan, & White, 2003; Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995; Bosch & Sebastián-Gallés, 2003; Cheour et al., 1998; Palmer, Fais, Golinkoff, & Werker, 2012; Pegg & Werker, 1997; Polka & Werker, 1994; Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005; Werker & Lalonde, 1988; Werker & Tees, 1984).

Infants growing up in nontone language environments display some perceptual narrowing for pitch between 4 and 9 months, but results are variable and depend on the salience of the contrast (e.g., Mattock & Burnham, 2006; Mattock, Molnar, Polka, & Burnham, 2008; Yeung, Chen, & Werker, 2013). For example, Mattock and Burnham (2006) found that between 6 and 9 months of age, English-learning infants lose the ability to discriminate rising versus low level Thai tones, but continue to discriminate the more acoustically salient distinction between rising and falling Thai tones. Yeung et al. (2013) found evidence of perceptual narrowing for the Cantonese high rising and the mid-level tone contrast between 4 and 9 months. However, they also suggested that language experience might affect the perception of lexical tone as early as 4 months. More research is needed to flesh out our understanding of perceptual narrowing of lexical tone.

To ensure that older English-learning infants continue to perceive the distinction between rising versus falling pitch contours in the 2nd year, Experiment 3 tested 19-month-olds' basic discrimination of the stimuli used in Experiments 1 and 2.

Experiment 3

In Experiment 3, we used a habituation/dishabituation procedure to test whether 19-month-olds can discriminate the tone contrasts used in Experiments 1 and 2. Previous research suggests that some pitch contours are subject to similar perceptual narrowing faced by segmental cues, such as vowels and consonants (e.g., Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013). However, we used rising versus falling pitch contours in the current set of experiments expressly because they appear to be less susceptible to perceptual narrowing (Mattock & Burnham, 2006), presumably because they are more acoustically salient (see the General Discussion). Consequently, we expected 19-month-olds to readily discriminate rising versus falling /kʊ/ when they were not attempting to associate the sounds with novel objects. This prediction is consistent with Stager and Werker's (1997) finding that although 14-month-olds cannot map minimal pairs such as /bIh/ and /dIh/ to novel objects, they readily discriminate the minimal pairs. On this account, discrimination is necessary, although not sufficient, for minimal pair mapping (see also Dietrich et al., 2007).

Method

Participants

Fourteen 19-month-old (M_{age} = 19.5 months, range = 18.2–20.4 months; seven female) monolingual English-learning infants participated in Experiment 3. Ten of the participants were from a small West Coast American city and four of the infants were from a mid-sized Southeastern American city. Exclusion criteria were identical to Experiments 1 and 2. Data from six additional infants were excluded from the analysis because of fussiness (four), experimenter error (one), or excessive movement (one).

Stimuli

The auditory stimuli were identical to those used in Experiments 1 and 2. The visual stimulus consisted of a static black and multicolored 9 × 14 in. checkerboard.

Procedure

The experiment started with a pretest trial (to familiarize infants with the task), followed by a habituation phase, a test phase, and a posttest trial (to ensure that performance on test trials was not a result of fatigue; see Werker et al., 1998). The pre- and posttest stimulus was a level pitch /la/ that was paired with a checkerboard. Following the pretest trial, infants were habituated to either rising /kʊ/ or falling /kʊ/ paired with the checkerboard. Assignment of habituation stimulus was counterbalanced across participants. As in Experiments 1 and 2, the words repeated until the infant looked away. The habituation criterion was also the same. Following habituation, infants were presented with two test trials. One trial was identical to the habituation trials (same trial). The other trial was a change trial where the auditory stimulus changed (i.e., from rising /kʊ/ to falling /kʊ/, or vice versa), but the visual display remained the same. The order of the test trials was counterbalanced such that half of the infants heard the same trial first, and half heard the change trial first.

Results and Discussion

All infants reached the habituation criteria. Preliminary analyses revealed that there were no main effects or interactions involving infant sex, habituation stimulus (rising vs. falling), or test order; all subsequent analyses were performed collapsed across these variables. To examine whether 19-month-old infants successfully discriminate rising /kʊ/ from falling /kʊ/, we compared mean looking time on same and change trials using a paired-samples t test. Analyses revealed that 19-month-olds looked significantly longer on the change trial (M = 5.17 s, SD = 1.38) than on the same trial (M = 4.53 s, SD = 1.21), $t(13) = 3.71$, $p = .003$, $d = .5$, indicating that they discriminated rising from falling lexical tone.

Thus, the failure to map minimally contrastive pitch contours to novel objects at 17 and 19 months of age does not appear to be due to perceptual narrowing for rising versus falling lexical tones. Instead, we suggest that between 14 and 17–19 months, monolingual English-learning infants experience an interpretive shift whereby differences in lexical tone cease to be lexically contrastive.

General Discussion

In the current experiments, we investigated the developmental trajectory of English-learning infants' use of pitch contour as lexically contrastive. The results suggest that infants become increasingly constrained in their interpretation of lexical tone across the 2nd year of life. In Experiment 1, 14-month-olds readily associated novel objects with two novel words that differed only in pitch contour. In Experiment 2, both 17- and 19-month-olds failed to map the same target words to the objects. Finally, in Experiment 3 we confirmed that older infants' performance on the label–object associations was not a result of perceptual narrowing; 19-month-olds readily discriminated rising from falling /kʊ/ when the labels were not presented with nameable objects.

These findings indicate that young English learners are not only sensitive to variations in pitch contour, but they display a remarkable ability to treat lexical tone contrastively during label–object mapping. Conversely, by 17–19 months of age, infants no longer interpret such variations as lexically relevant, although they continue to be sensitive to variations in pitch contour when the mapping problem is eliminated. Thus, the developmental shift in flexibility occurs sometime between 14 and 17–19 months, as infants gain experience with the functions of segmental and suprasegmental units in their language. More broadly, our results support the idea that infants begin the process of word learning flexible in their interpretation of which sound variants are lexically contrastive (e.g., Woodward & Hoyne, 1999), and show language-appropriate constraints as they gain linguistic knowledge (e.g., Fulkerson & Waxman, 2007; Graf Estes, Edwards, & Saffran, 2011; Waxman & Booth, 2003; Woodward & Hoyne, 1999).

Younger children do not typically outperform older children. Some of the domains in which this unusual developmental pattern occurs include face processing (e.g., Kelly et al., 2007; Scott, Pascalis, & Nelson, 2007) and speech perception (e.g., Werker & Tees, 1984). In face processing, infants at 3 months of age perceive distinctions between faces of unfamiliar races that 9-month-olds do not readily discriminate (Kelly et al., 2007). In speech perception, 6-month-olds detect differences between non-native phonemes that 10-month-olds do not readily detect (Werker & Tees, 1984). As infants gain experience in particular domains, their perceptual systems narrow to focus on the distinctions that are predominant in the ambient environment. This allows for more efficient processing of the information that is most likely to be relevant to the infants' interactions with others, but results in less effective processing for non-native patterns.

The present experiments have a great deal in common with the findings regarding perceptual narrowing. Younger infants showed word learning superior to what we observed with older infants. This decline in performance is adaptive; in order to process English effectively, it is important to treat words that differ only in pitch contour as variations of the same word. In face processing, speech perception, and learning of labels that differ in lexical tone, the developmental shift occurs as infants become more specialized for processing the input present in their environments. However, the present experiments do not demonstrate perceptual narrowing per se. As Experiment 3 showed, infants can readily perceive the distinction between the rising and falling tones when no objects are present, at least as late as 19 months of age. The key is that English-learning infants do not treat these pitch contours as functionally significant in word learning. We have demonstrated an interpretive narrowing: With linguistic experience, infants become increasingly specific about the forms of words that they treat as lexically contrastive.

The present findings integrate with previous work addressing the connection between phoneme perception and word learning (Apfelbaum & McMurray, 2011; Dietrich et al., 2007; Galle et al., in press; Pater et al., 2004; Rost & McMurray, 2009, 2010; Stager & Werker, 1997; Werker & Curtin, 2005; Werker et al., 2002) to provide a rich picture of the effects of phonological development on word learning. Infants must learn which sound variants in the ambient environment signal meaningful contrasts between words. In some circumstances, infants must take sound distinctions that they perceive (e.g., /pIn/ vs. /bIn/) and develop sufficiently robust representations of them to determine that the sounds make meaningful distinctions between words. In other cases, infants may perceive that sounds are distinct (e.g., different pitch patterns or vowel durations), but they must learn not to treat the perceptual distinction as functionally significant. This balancing of attention is essential for rapid and effective word learning and word recognition.

The discussion of interpretive narrowing that we have offered suggests that infants become more constrained in what they accept as possible words as they accrue language experience. Numerous studies, however, have suggested that infants begin word learning with strong constraints on the sound variants that they interpret as good object labels (e.g., MacKenzie et al., 2011; MacKenzie et al., 2012). Why, then, did the 14-month-olds in Experiment 1 display flexibility in interpretation of pitch contours? The answer may be multilayered. First, infants have considerable experience with the ways that pitch contour varies meaningfully in English. Thus, by 14 months of age, infants may have gleaned that pitch contour is meaningfully relevant. However, they may still have to develop the sophisticated knowledge that pitch is not used contrastively for word meaning in English and assign pitch variations to their appropriate linguistic functions (see also Dietrich et al., 2007).

Second, the labels used here contain rich acoustic properties that may facilitate learning. As mentioned previously, rising versus falling tones seem to resist perceptual narrowing during the 1st year of life (Mattock & Burnham, 2006), presumably due to their acoustic salience (for a discussion of the connection between acoustic salience and the timing of perceptual narrowing, see Narayan et al., 2010; Yeung et al., 2013). Thus, these acoustically salient tone contours may support label–object mapping relative to less salient contrasts (Curtin, Fennell, & Escudero, 2009; Graf Estes & Hurley, 2013; Stager & Werker, 1997). In addition, lexical tones unfold over several hundred milliseconds and have broad pitch ranges. In contrast, the segmental differences in minimal pairs such as /bIh/ and /dIh/ unfold over tens of milliseconds; thus, there is significantly less information available to the listeners during the labeling task. Hence, the development of attention to phonemic-based minimal pairs may differ from pairs that differ in a variety of suprasegmental characteristics, including pitch contour and stress (for evidence of stress-based minimal pair mapping, see Curtin, 2009). During the early process of discovering which acoustic properties of sounds in the environment make meaningful distinctions between words, infants may initially rely more heavily on acoustic salience. As infants gain linguistic experience, they may begin to weight native language lexical properties more than acoustic salience (see also Dietrich et al., 2007; Galle et al., in press; Rost & McMurray, 2009, 2010). Future research will be necessary to directly explore the role of acoustic salience in label–object mapping.

The current set of studies informs our understanding of flexibility and constraint in early word learning. They reveal the time course of interpretive narrowing of lexical tone across the 2nd year of life. Even in the absence of social or referential support, young monolingual English-learning infants treat syllables with distinct tonal contours as labels for distinct objects. Their success is surprising given the difficulty that infants around this age typically experience mapping minimal pair words to novel objects (Pater et al., 2004; Stager & Werker, 1997; Werker et al., 2002) as well as a variety of communicative and noncommunicative mouth sounds (MacKenzie et al., 2011), and sound sequences that are phonotactically illegal (MacKenzie et al., 2012). We propose that flexibility and constraint in early word learning emerge from a confluence of factors including acoustic salience and the quantity and nature of the linguistic experience. For example, recent work suggests that bilinguals may have a protracted period of flexibility during early label–object mapping compared to monolinguals (Graf Estes & Hay, 2014). Further research is needed to establish the relative roles of each of these factors in interpretive narrowing. Lexical tone provides a unique lens through which to study these relations.

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