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Flexibility in Bilingual Infants' Word Learning

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The present experiments tested bilingual infants' developmental narrowing for the interpretation of sounds that form words. These studies addressed how language specialization proceeds when the environment provides varied and divergent input. Experiment 1 (N = 32) demonstrated that bilingual 14- and 19-month-olds learned a pair of object labels consisting of the same syllable produced with distinct pitch contours (rising and falling). Infants' native languages did not use pitch contour to differentiate words. In Experiment 2 (N = 16), 22-month-old bilinguals failed to learn the labels. These results conflict with the developmental trajectory of monolinguals, who fail to learn pitch contour contrasts as labels at 17–19 months (Hay, Graf Estes, Wang, & Saffran, 2015). Bilingual infants exhibited a prolonged period of flexibility in their interpretation of potential word forms.

A majority of children worldwide learn more than one language (Grosjean, 2010). Yet, much of what we understand about early language acquisition is derived from studies of monolingual children. There are many broad similarities between monolingual and bilingual development that highlight the impressive nature of bilingual learning. For example, despite the additional computational demands of acquiring two separate linguistic systems, bilinguals meet many language milestones, such as first words, at around the same ages as monolinguals (e.g., Oller, Eilers, Urbano, & Cobo-Lewis, 1997; Pearson, Fernandez, & Oller, 1993; Petitto et al., 2001). Furthermore, monolinguals' and bilinguals' total vocabulary sizes are comparable when all of the words bilinguals know across languages are included in the count (Hoff et al., 2012; Pearson et al., 1993; Petitto et al., 2001). Beyond these gross similarities, young bilinguals and monolinguals display some intriguing differences in their patterns of development (see reviews by Byers-Heinlein & Fennell, 2014; Sebastián-Gallés, 2011). In the present experiments, we explore the possibility that bilingual experience may promote extended flexibility in early word learning.

At the phonological level, monolingual and bilingual infants must discover the phoneme boundaries, phoneme combinations, allophonic variations, word boundaries, and the rhythmic patterns of the words and sentences of their native language(s). This is a demanding process because infants have no a priori knowledge of which sound variants (including phonemes and allophones, as well as pitch, duration, and phonotactic patterns) are relevant in their native languages, or how these sound variants will be used. Bilingual infants, however, have the added challenge of determining how sound variants are used in two systems instead of one. In the bilingual literature, there are inconsistent findings regarding the time course of phonological development, and the course of perceptual narrowing, more specifically. In language acquisition, *perceptual narrowing* entails two complementary processes: perceptual attenuation of some non-native phoneme contrasts coupled with perceptual maintenance or enhancement of native-language contrasts (e.g., Kuhl et al., 2006; Werker & Tees, 1984). There are findings that suggest bilinguals take longer than monolinguals to home in on language-specific phoneme categories (Bosch & Sebastián-Gallés, 2003b; Sebastián-Gallés & Bosch, 2009). For example, across the 1st year of life, bilingual Spanish-Catalan infants show a U-shaped function

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for both Catalan vowel (i.e., /e/–/ε/contrast) discrimination (Bosch & Sebastián-Gallés, 2003b) and consonant (/s/–/z/contrast) discrimination (Bosch & Sebastián-Gallés, 2003a). At an intermediate age, bilingual infants appear to lose the ability to discriminate contrasts that younger and older infants can discriminate. Monolinguals do not show this same U-shaped function. Bosch and Sebastián-Gallés (2003b) proposed that monolingual and bilingual input produce different courses for the language-specific reorganization of the perceptual system. As discussed in more detail below, bilinguals receive less input in a given language than monolinguals receive, and the phoneme category boundaries within and across languages are less clear than in monolingual input. Bilinguals may need to accumulate additional exposure to form strong expectations about phoneme categories. However, other evidence indicates that bilinguals and monolinguals show similar patterns of development in speech perception (Albareda-Castellot, Pons, & Sebastián-Gallés, 2011; Burns, Yoshida, Hill, & Werker, 2007; Sundara, Polka, & Molnar, 2008). The observed patterns seem to depend greatly on the procedures and measures implemented, the attentional demands required to solve the task, and the languages and types of contrasts studied (for reviews, see Byers-Heinlein & Fennell, 2014; Curtin, Byers-Heinlein, & Werker, 2011; Sebastián-Gallés, 2011).

The varied behavioral findings regarding phonological development leave open the possibility that perceptual narrowing takes place over different developmental periods for bilingual and monolingual infants. There is recent neural evidence supporting this possibility. In an experiment using event-related brain potentials, Garcia-Sierra et al. (2011) tested Spanish-English bilingual infants' discrimination of Spanish and English consonants. Bilingual infants exhibited neural discrimination at 10–12 months of age, but not at 6–9 months of age. In contrast, English-learning monolinguals showed neural discrimination of both native and non-native contrasts at 7 months of age, but only of native contrasts at 11 months (Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005). Garcia-Sierra et al. (2011) suggested that it may take longer for bilingual infants to establish language-specific neural commitment from their broad (language-universal) perceptual abilities. Further support for this notion was reported in an experiment using functional near infrared spectroscopy. Petitto et al. (2012) indicated that across development, bilingual infants tended to show similar patterns of activation of left inferior frontal cortex for native and non-native (Hindi) phoneme contrasts. In contrast, across the same developmental period (around 4–6 months vs. 10–12 months), monolinguals' activation diverged for native and non-native contrasts.

There are several reasons why bilingual phonological development may show different patterns than monolingual development (Byers-Heinlein & Fennell, 2014; Costa & Sebastián-Gallés, 2014; Curtin et al., 2011). First, bilingual infants likely hear less speech in each language than monolinguals hear in a single language. Second, there are greater computational demands in learning two separate phonological, lexical, and syntactic systems than in learning a single system. Infants must track information in each language separately to learn the distinct systems. They must also discern, moment to moment, which language is relevant in the immediate context. Third, the languages may divide the same acoustic space into different categories; bilinguals may be required to interpret conflicting cues to sound structure or interpret the same sound differently depending on the context. Finally, Byers-Heinlein and Fennell (2014) described bilingual input as "noisy" and highly variable (see also Garcia-Sierra et al., 2011). One source of noise occurs because many bilingual infants hear two different languages produced by the same person, sometimes even within the same sentence (Byers-Heinlein, 2013), thereby potentially making it difficult to process sound patterns separately in each language. In addition, many bilingual children learn from parents who are themselves bilingual. Thus, there may be greater variability in the acoustic realization of some speech sounds in bilingual input (Sundara, Polka, & Baum, 2006) and an increase in the frequency of production errors compared to monolingual input (Bosch & Ramon-Casas, 2011). Noise in the input may make it challenging to determine how to weight acoustic-phonetic dimensions of the speech signal to focus on what is critical for differentiating between words with different meanings.

Infants' learning about the sound inventory of their language(s) ultimately serves the process of linking sounds (word forms) with meanings during word learning. How do bilingual infants apply their early learning about sounds to acquire words? Studies of early lexical development suggest that bilinguals differ in their attention to phonetic detail in words relative to monolinguals. For example, Ramon-Casas, Swingley, Sebastián-Gallés, and Bosch (2009) reported that during word recognition, bilingual toddlers did not detect mispronunciations of vowels found in highly familiar words when the vowels were contrastive in only one of their languages, whereas monolinguals readily detected such native mispronunciations in their own language.

Curtin et al.'s (2011) Processing Rich Information from Multidimensional Interactive Representations (PRIMIR) framework suggests that bilingual infants face different demands when mapping sounds to meanings than do monolinguals. Demands such as reduced input, crowded phonetic space, and language switching may tax the limited resources available for attending to fine phonetic detail while simultaneously mapping sounds to meaning. In a novel word learning task, Fennell, Byers-Heinlein, and Werker (2007) examined bilinguals' learning of minimal pair object labels that differed by a single phoneme (i.e., /bI/and/dI/). At 14 months of age, monolinguals typically fail to learn such labels in the absence of supportive referential context, but by 17 months they typically succeed even without the support (e.g., Werker, Fennell, Corcoran, & Stager, 2002). Fennell et al. (2007) found that it took bilingual infants an additional 3 months before they succeeded at the same task; 17-month-old bilinguals did not learn the labels, but by 20 months they succeeded (but see Fennell & Byers-Heinlein, 2014; Mattock, Polka, Rvachew, & Krehm, 2010, for task-related effects).

Similar to the development of perceptual narrowing, bilingual experience may affect word learning by requiring more time to develop strong representations of the ways that sounds can differentiate between words (i.e., abstract phoneme representations; Curtin et al., 2011; Werker & Curtin, 2005). Exposure to two phonological systems may require a protracted period of development to determine what information is relevant during word learning and what is not. That is, bilinguals may take more time than monolinguals to center on what sound variants are lexically contrastive and can therefore distinguish words. This may contribute to bilinguals' later learning of minimal pairs, relative to monolinguals in the equivalent task (Fennell et al., 2007; Werker et al., 2002). In addition, the developmental difference may mean that in some circumstances, bilinguals may be *more* inclusive than monolinguals regarding the types of sound variants that can map to meanings, particularly if those sounds are acoustically salient and have not been assimilated to native sound categories.

In the present experiments, we test the hypothesis that bilingual experience may promote an extended period of flexibility during early word learning. Across domains, narrowing that occurs throughout development is thought to reflect specialization for processing the infant's particular environment (Scott, Pascalis, & Nelson, 2007). As discussed earlier, infants display perceptual narrowing for phoneme categories, focusing on the sounds that occur in their native language(s). Later in acquisition, infants also exhibit *interpretive narrowing* in word learning (Hay et al., 2015), in which they constrain the range of sounds (e.g., beeps, communicative vocal sounds) and sound sequences (e.g., phonotactically unattested combinations) that can be mapped to meanings (Graf Estes, Edwards, & Saffran, 2011; Namy, 2001; Woodward & Hoyne, 1999). The openness or flexibility that has been proposed in bilingual phoneme category perception (Garcia-Sierra et al., 2011; Petitto et al., 2012) may extend to word learning as well. Thus, the developmental course of interpretive narrowing in word learning may differ for monolinguals and bilinguals.

Although protracted interpretive narrowing may occur hand in hand with protracted perceptual narrowing, there are additional factors that may apply specifically to flexibility in word learning. First, there is a greater diversity in the potential forms that words can take in bilingual environments as compared to monolingual environments. The phonemic and phonotactic inventories across two languages are broader than the inventories of a single language, and this breadth of word forms may encourage bilingual infants to entertain a wide range of potential word forms.

There are also factors outside of the phonological system that could affect flexibility. Although both monolingual and bilingual infants learn to map sound sequences onto objects in their environments, bilinguals frequently must accept more than one label for an individual concept. Accordingly, bilinguals do not apply mutual exclusivity (or disambiguation) as stringently as monolinguals (Bialystok, Barac, Blaye, & Poulin-Dubois, 2010; Byers-Heinlein & Werker, 2013). Finally, because bilinguals must switch between languages, they must simultaneously activate one phonological system and inhibit the other, while maintaining connections between each language and an underlying conceptual system. Research suggests that this demanding process may lead to enhanced cognitive flexibility in early child development (Kovacs & Mehler, 2009; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011) and in early and later adulthood (Bialystok, Craik, & Luk, 2008) for tasks that require attentional control, shifting attention, and inhibition. Here, we explore the possibility that bilingual experience may also promote flexibility regarding the sounds that can be mapped to meanings in early word learning.

There are several important criteria for the selection of stimuli to produce a strong test of flexibility in the sounds that bilinguals attend to during word learning. First, the sound variants involved should be acoustically salient, so that any lack of label learning cannot be attributed to a failure to perceive differences between labels or due to the challenges of attending to small phonetic details while simultaneously mapping sounds to objects. Second, the labels should form naturalistic possible words, so that infants' prior experience with word forms is not violated. Third, to produce a naturalistic test, the labels should consist of sound variants that are used to differentiate words in some languages, but not in the infants' native languages.

Given these criteria, pitch contour serves as an excellent means to examine flexibility in word learning in bilinguals. Around 60%–70% of the world's languages are tonal languages (Yip, 2002), meaning that speakers can use differences in pitch contour (i.e., lexical tone) to differentiate word meanings. For example, in Mandarin Chinese the syllable /ma/ produced with a high level contour (Tone 1) means "mother," but produced with a low dipping contour (Tone 3) means "horse." For English learners, and learners of other nontonal languages, pitch contour is a highly salient and familiar component of the speech stream, but it is used quite differently than in tonal languages. Variations in pitch can signal emotion (Murray & Arnott, 1993), grammatical structure (Gussenhoven, 2004), lexical stress (Fry, 1958), speaker identity, emphasis, and speaking register (e.g., infant- vs. adult-directed speech; Fernald, 1992). Thus, infants have experience with pitch variation, but none of this experience indicates that words can differ by pitch contour alone.

In tone perception tasks, there is evidence that perceptual narrowing occurs for some tone contrasts quite early in development. For example, Yeung, Chen, and Werker (2013) presented 4- and 9-month-old English-learning infants with two distinct pitch contours (high rising and mid level tones) that are used to distinguish word meanings in Cantonese. They found that 4-month-olds, but not 9-month-olds, differentiated the tones (see also Mattock, Molnar, Polka, & Burnham, 2008). However, other tone contrasts appear to be resistant to perceptual narrowing. For example, Mattock and Burnham (2006) demonstrated that while English-learning infants lose the ability to discriminate Thai rising and low tones between 6 and 9 months of age, they continue to discriminate Thai rising and falling tones throughout this period (see also So & Best, 2010, for additional evidence of contrast-dependent lexical tone discrimination). Perceptual narrowing appears to depend, at least in part, on how acoustically distinctive or confusable the tones are. The distinctiveness of rising versus falling tones, for example, makes them more resistant to perceptual narrowing than some other contrasts.

Although lexical tones vary in how acoustically distinctive they are, infants learning nontonal languages should come to ignore pitch contours when mapping labels to objects. There should be interpretive narrowing regarding pitch contours in label learning because the input indicates that differences in pitch contour do not differentiate words. Two recent word learning studies provide evidence of changing sensitivity to pitch contour across the 2nd year of life. Hay et al. (2015) investigated monolingual English-learning 14-, 17-, and 19-month-olds' ability to learn a pair of object labels that differed only in their pitch contours (i.e., the syllable *ku* produced with a rising vs. falling contour). Using a modified version of the Switch paradigm (Werker, Cohen, Lloyd, Casasola, & Stager, 1998), infants were habituated to two label-object pairings, then tested on trials in which the original pairings were maintained and on trials in which the original pairings were switched. Longer looking on the test trials in which the pairings were switched indicated that the infants learned the labels. Hay et al. found that only 14-month-olds readily detected the altered test trials, indicating that they learned identical syllables with distinct pitch contours as separate object labels. Seventeen- and 19-month-olds did not. Thus, English-learning novice word learners are open to accepting object labels that differ only in pitch contour, whereas infants just a few months older have narrowed their interpretation of what sounds are lexically contrastive.

Singh, Hui, Chan, and Golinkoff (2014) found somewhat later interpretive narrowing for pitch contour in both monolinguals and bilinguals. They tested three groups of 18- and 24-month-olds: monolingual English learners, Mandarin learners also acquiring English, and bilinguals acquiring two nontonal languages. Within a referential context (i.e., "Look here! It's a ____!"), infants were familiarized with two object labels that differed in both initial consonant and pitch contour (*leng* rising vs. *beng* falling). During testing, the labels changed in pitch contour (i.e., *leng* rising → *leng* falling). Mandarin-learning 18- and 24-month-olds detected the altered pitch contours. However, English-learning infants and bilingual nontonal language learners detected the altered pitch contours at 18 months, but not at 24 months. Thus, younger nontonal language learners attended to pitch contour, treating it as a lexically contrastive feature. By 24 months, only infants who had experience with tonal languages attended to the alteration in the words' pitch contours.

Across studies, there is a discrepancy regarding monolingual infants' attention to pitch contour during word learning around 1.5 years of age. Hay et al. (2015) found evidence of interpretive narrowing between 14 and 17–19 months of age, whereas Singh et al. (2014) found continued flexibility at 18 months. Differences in the demands of each task may have produced the conflicting findings (Curtin et al., 2011; Werker & Curtin, 2005) and may affect our understanding of bilingual word learning as well. Singh et al.'s task provided naturalistic referential context in the labeling phrases and through the inclusion of familiar objects. The supportive context may have promoted attention to detail in the input (Fennell & Waxman, 2010), thereby supporting (and perhaps overestimating) infants' attention to the non-native use of pitch contour in the new words. Consistent with this notion, May and Werker (2014) found that a task with referential cues supported infants' learning of labels containing non-native click contrasts, whereas a Switch task lacking referential cues did not.

Singh et al.'s (2014) results suggest later interpretive narrowing for monolinguals (between 18 and 24 months) and equivalent flexibility or openness in processing for monolingual and bilinguals. Conversely, relatively pared down tasks that lack referential cues, like the Switch paradigm used by Hay et al. (2015) and others (e.g., Stager & Werker, 1997), may be better able to reveal the early stages of experience-induced interpretive narrowing because they provide less attentional push. Indeed, the monolingual English-learning infants in Hay et al.'s study processed pitch in a way that actually appears to be more sophisticated (i.e., ignoring pitch contour differences when learning a nontonal language), displaying interpretive narrowing by 17 months. In this case, the task lacking referential support revealed aspects of word learning that were hidden by the more supportive context (Singh et al., 2014).

The comparisons across the research and Hay et al. (2015) and Singh et al. (2014) illustrate two important ideas. First, although progress has been made (Curtin et al., 2011; Fennell & Waxman, 2010; May & Werker, 2014), we do not fully understand how the dynamics of experimental tasks affect language processing. Second, the comparisons demonstrate the importance of examining development using multiple methodologies. Based on this literature, it is not clear whether bilingual infants also undergo early interpretive narrowing for pitch contour because they have only been tested in a referential task (Singh et al., 2014), which may have overestimated similarities between monolinguals' and bilinguals' interpretation of pitch contour during word learning.

As discussed above, there are many reasons to expect that bilinguals might display a protracted period of flexibility in word learning. In particular, they may show interpretive narrowing at a later age than monolinguals because their phonological input is more variable and is divided across two distinct systems, and they receive experience with a broader range of ways that sounds can differentiate words than monolinguals experience. In addition to these potential causal mechanisms for a protracted period of flexibility, it would be functionally adaptive for bilinguals to remain open to accepting a wider variety of sound distinctions as labels for novel objects (see also Garcia-Sierra et al., 2011; Petitto et al., 2012). Importantly, a prolonged period of interpretive narrowing may leave bilinguals open to accepting less attested, but phonologically legal, distinctions as they continue to gather information about how sounds are used in each language.

In the present experiments, we investigated the trajectory of bilinguals' processing of a salient, communicatively relevant aspect of the speech signal that is not used to differentiate words in either of the infants' native languages. Experiment 1 examined bilingual 14- and 19-month-olds' interpretation of pitch contour as a means to differentiate words. The experiment tested whether nontonal language bilinguals show the same developmental shift as English-learning monolinguals when learning object labels that contrast only in pitch contour (Hay et al., 2015). We used the stimuli and methodology presented by Hay et al. (2015) to test whether, in the absence of referential support, bilinguals show early interpretive narrowing in word learning, like monolinguals in the same task, or whether they show a protracted period of attention to pitch contour. Infants were presented with a pair of novel objects and novel labels that consisted of the same syllable, *ku* (/kʊ/), produced with a rising pitch contour in one object label and with a falling pitch contour in the second object label.

If bilingual infants are not yet fully committed to the sound variants that differentiate words in their native languages, they may remain open to learning labels that differ only in pitch contour for longer than their monolingual peers. In Experiment 1, we predicted that bilingual infants would learn labels that differed only in pitch contour at both 14 and 19 months of age. In contrast, monolingual infants experience a shift in their interpretation of pitch contour between 14 and 19 months of age (Hay et al., 2015).

Experiment 1

Method

Participants

The participants were 16 bilingual infants aged 14 months (M = 14.5 months, range = 13.9–15.1 months; 8 female) and 16 bilingual infants aged 19 months (M = 19.7 months, range = 19.0–20.6; 8 female). All infants were born full term and had no history of hearing or vision impairments. Based on a parental report questionnaire and interview, each infant heard English for between 25% and 75% of their language exposure and a second language for the remaining 75%–25%. These language exposure criteria are similar to other recent word learning studies with bilingual infants (Byers-Heinlein, Fennell, & Werker, 2013; Fennell et al., 2007). The average exposure to English was 48% and 51% for the 14- and 19-month-olds, respectively. Crucially, none of the infants' other languages used pitch contour contrastively. They were all nontonal languages, according to the *World Atlas of Language Structures* (Dryer & Haspelmath, 2011). In the 14-month-old group the languages were: Arabic (1), Bengali (1), French (2), Spanish (11), and Tongan (1). In the 19-month-old group the languages were: Amharic (1), French (1), Italian (3), Portuguese (1), and Spanish (10). Twelve additional infants were excluded from analyses because of fussiness or crying (7), moving out of the video frame (3), parental interference (1), or being distracted by an object during testing (1). One 19-month-old was identified as an outlier (looking time difference over 2.5 SD from the mean) and was excluded from analyses.

For Experiments 1 and 2, the demographics of the sample were: 38% White/Caucasian, 19% Mixed Race, 11% Black/African American, 2% Asian, 17% Other, and 13% not reported; 57% of the participants were Hispanic. All infants were tested between 2012 and 2014 in a small city in Northern California (Davis, CA). Infants were recruited from a database of families in the region who had expressed interest in participating in research.

Stimuli

The stimuli were identical to the stimuli that Hay et al. (2015) designed for testing monolingual infants. The labels consisted of the syllable *ku* (/kʊ/) produced by a female native Mandarin Chinese speaker with a rising pitch contour (Mandarin Tone 2) and a falling pitch contour (Mandarin Tone 4). Figure 1 shows a spectrogram of each label with the fundamental frequency (F0, a measure of pitch) displayed. The voiced portion of the rising *ku* began with a frequency of 245 Hz, fell to 200 Hz over the first 130 ms of voicing, then rose to 290 Hz over the remainder of the syllable. The voiced portion of the falling *ku* began with a frequency of 320 Hz, which fell to 190 Hz over the remainder of the syllable. Total durations of the labels were similar (rising *ku* = 856 ms; falling *ku* = 867 ms). Tokens were repeated with 750 ms of silence separating them. Auditory stimuli were presented at 65 decibels (dB) of sound pressure level, the same intensity used by Hay et al. (2015).

As shown in Figure 2, the novel objects were three-dimensional images designed to differ in

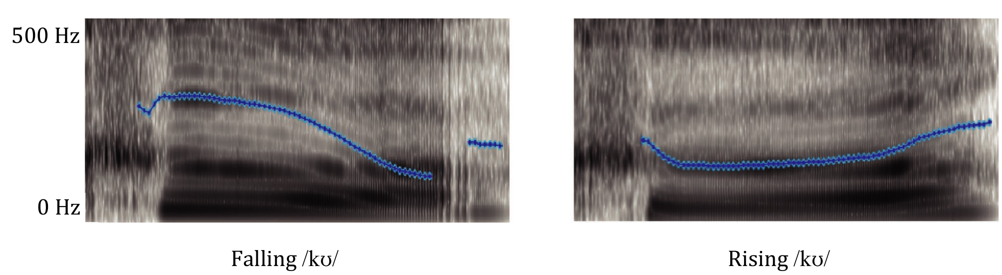
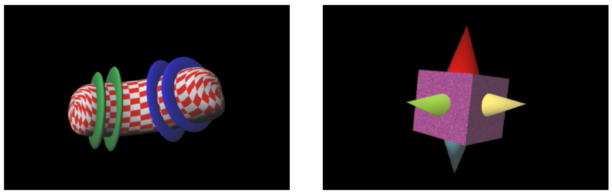


Figure 1. Spectrogram and pitch contours of falling /kʊ/ (left) and rising /kʊ/ (right).



Object 1 Object 2

Figure 2. Objects used in label-object association task.

color, shape, and texture. Each object moved slowly from left to right across a black rectangle at the center of a television screen. The movement was not synchronized with the labels. Infants were randomly assigned to view Object 1 paired with rising *ku* and Object 2 paired with falling *ku*, or vice versa. The objects, along with their movement and presentation relative to the auditory signal, were identical to those used by Hay et al. (2015).

Procedure

The procedures, including the basic laboratory setup, the number of habituation and test trials, the trial duration, and the habituation criterion used here, were also the same as those used by Hay et al. (2015). Each infant was seated on a parent's lap in a sound-attenuated booth, approximately 1 m from a television with integrated speakers. A camera mounted below the screen was connected to an external monitor that allowed the experimenter to view the infant's responses. The program Habit X (Cohen, Atkinson, & Chaput, 2004) was used to present the audiovisual stimuli on the television and measure looking time. The experimenter indicated when the infant looked at the stimuli using a button press on the computer running Habit. To avoid bias, the parent listened to masking music on headphones and the experimenter was blind to the stimuli being presented.

The infant first viewed a pretest trial intended to familiarize him or her with the nature of the audiovisual task. During this trial, a novel object was paired with the syllable /la/ produced with a level pitch.

We used a modified version of the Switch task (Werker et al., 1998), which measures infants' ability to acquire novel associations between word forms and referents (see also Fennell et al., 2007; Graf Estes & Bowen, 2013; Werker et al., 2002). Each trial began with an animated cartoon clip to guide attention to the screen. Label learning took place during habituation trials. During each habituation trial, when the infant looked, a label–object pairing was presented. Each trial continued until the infant looked away for at least 1 s, or for a maximum of 20 s. The presentation of the two label–object pairings was randomized by block until the infant met the habituation criterion: Looking time across three consecutive trials (in a sliding window) decreased to 50% of the mean looking time across the first three trials. Using a sliding window and presenting the label–object pairs with the order randomized by block ensured that infants advanced to the test phase once they habituated, while maintaining very similar numbers of habituation trials (maximum difference of one) for each label–object pair.

The test trials immediately followed habituation. There were two types of test trials: same trials in which the original label-object associations were maintained and switch trials in which the familiar labels and objects occurred in new pairings. For example, during habituation and same trials Object 1 occurred with rising *ku*, and on switch trials Object 1 occurred with falling *ku*. There were two blocks of four test trials; each block contained two same trials and two switch trials. Infants were randomly assigned to participate in one of eight pseudo-randomized test orders that counterbalanced the presentation of same and switch trials. Preliminary tests indicated no effects of test order or test block therefore analyses collapsed across these variables. The rationale behind the task is that if infants learned the label–object pairings during habituation, they should look longer during switch test trials when those pairings are violated. Several previous experiments using the Switch task have presented only two test trials (one same trial, one switch trial; e.g., Fennell et al., 2007; MacKenzie, Graham, & Curtin, 2011; Werker et al., 1998). We used eight trials to maintain consistency with the method that Hay et al. (2015) used, which is also similar to several prior experiments (Graf Estes & Bowen, 2013; Graf Estes, Evans, Alibali, & Saffran, 2007; Hay, Pelucchi, Graf Estes, & Saffran, 2011).

Results and Discussion

The 14-month-olds met the habituation criterion following a mean of 12.6 trials (SD = 4.7), accumulating a total looking time during habituation of 137.2 s (SD = 61.2). The 19-month-olds met the habituation criterion following a mean of 9.3 trials (SD = 3.6, accumulating a total looking time during habituation of 106.4 s (SD = 56.8). All infants met the habituation criterion. Although the 19-month-olds habituated in fewer trials than the 14-month-olds, $t(30) = 2.25$, $p = .032$, $d = 0.80$, there was no significant difference in the total looking time during habituation, $t(30) = 1.47$, $p = .152$, $d = 0.52$.

To examine infants' learning of the labels, 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) of infants' looking time. There was no main effect of age ($F < 1$) and no interaction of Age × Trial Type, ($F < 1$). There was a significant effect of trial type, $F(1, 30) = 10.77$, $p = .003$, $\eta_p^2 = .26$. Across age groups, infants looked longer during switch trials ($M = 8.6$ s, $SD = 3.3$) than same trials ($M = 7.0$ s, $SD = 2.4$).

The ANOVA did not reveal any difference in performance based on age. The pattern contrasts with Hay et al.'s (2015) recent findings using the same stimuli, in which 14-month-old monolinguals learned the labels, but 19-month-olds did not. To confirm that our results indeed reflected that infants at both ages learned the label–object associations, we performed paired samples t tests for each age group. As Figure 3 illustrates, infants in each age group looked significantly longer during switch trials compared to Same trials: 14 months, $t(15) = 2.28$, $p = .038$, $d = 0.63$, and 19 months, $t(15) = 2.57$, $p = .021$, $d = 0.52$. Thus, infants at 14 and 19 months of age reliably detected when the label–object pairings were switched, indicating that they successfully learned the new object labels.

The results described above suggest that bilingual infants displayed a different pattern of word learning than has been found in monolingual English-learning infants (Hay et al., 2015). To determine whether the bilingual pattern is reliably different from the monolingual pattern, we performed statistical comparisons with the data from Hay et al.'s (2015) work, which used the same procedures. At 14 months of age, a 2 (language background: monolingual vs. bilingual; between subjects) × 2 (trial type: same vs. switch; within subjects) mixed ANOVA of infants' looking time revealed no main effect of language background ($F < 1$) and no significant interaction ($F < 1$), but there was a significant effect of trial type, $F(1, 38) = 9.36$, $p = .004$, $\eta_p^2 = .20$. Across language backgrounds, 14-month-olds consistently displayed longer looking during switch trials. At 19 months of age, there was a different pattern. A 2 (language background) × 2 (trial type) mixed ANOVA of infants' looking time revealed no main effects of language Background ($F < 1$) or trial Type ($F < 1$). There was a significant Language background × Trial type interaction, $F(1, 38) = 4.41$, $p = .042$, $\eta_p^2 = .10$. The interaction confirms that 19-month-old monolinguals and bilinguals showed different looking patterns. Bilinguals tended to detect when the label–object pairings were switched, whereas monolinguals did not.

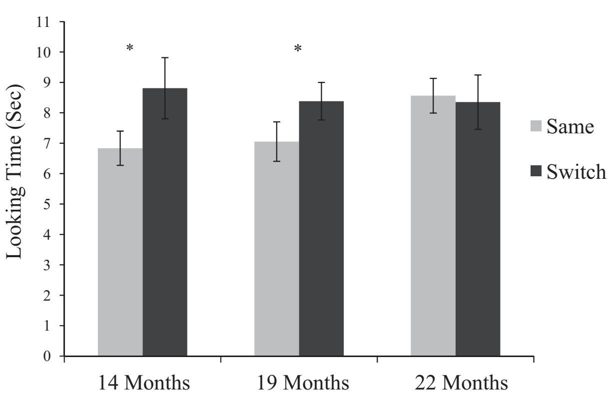


Figure 3. Mean looking time (in seconds) to same and switch test trials. Error bars represent standard errors. Asterisks indicate same versus switch trial looking times that are significantly different, $p < .05$.

Experiment 2

Experiment 1 indicated that bilingual infants did not show the same pattern of narrowing in their interpretation of pitch contour that monolinguals displayed in the same task and with the same stimuli (Hay et al., 2015). At 19 months of age, bilinguals seem to be more flexible than monolinguals in their interpretation of the sound variants that can differentiate words. In Experiment 2, we tested bilingual infants who have had several additional months of experience with their nontonal languages, 22-month-olds. We predicted that bilingual infants who are close to their second birthdays may have accumulated sufficient experience with how pitch is used in their native languages to rule it out as a means to differentiate words. Thus, by 22 months, they may show constraint in their interpretation of pitch contour in new words.

Method

Participants

The participants were 16 bilingual 22-month-old infants ($M = 22.5$ months, range = 22.0–23.5 months; 9 females). The infants met the same health and language inclusion criteria as in Experiment 1. The mean exposure to English was 55%. The nontonal second languages infants were exposed to were: French (3), Nepali (1) Spanish (11), and Tongan (1). Nine additional infants were excluded from analyses because of fussiness or crying (7) or parental interference (2).

Stimuli and Procedure

The stimuli and procedure were identical to Experiment 1.

Results and Discussion

Infants met the habituation criterion following a mean of 8.6 trials (SD = 3.1), accumulating a total looking time during habituation of 100.9 s (SD = 44.3). All infants met the habituation criterion. The 22-month-olds habituated in fewer trials than the 14-month-olds in Experiment 1, $t(30) = 2.82$, $p = .008$, $d = 1.02$. The 22-month-olds also had a marginally shorter total time to habituate, $t(30) = 1.19$, $p = .065$, $d = 0.69$. However, the 22-month-olds did not differ from the 19-month-olds in Experiment 1 in trials to habituate, $t(30) = 0.531$, $p = .599$, $d = 0.18$, or time to habituate, $t(30) = 0.307$, $p = .761$, $d = 0.11$. Interestingly, for all age groups, there were no significant correlations between trials or time to habituate and the magnitude of infants' preference for switch trials (all ps > .14). Thus, any differences in label learning performance cannot be attributed to differences in habituation.

To examine infants' learning, we performed a paired samples t test comparing looking time to same versus switch test trials. As shown in Figure 3, there was no significant difference in looking time, $t(15) = 0.229$, $p = .822$, $d = 0.07$. This suggests that the 22-month-old bilinguals did not learn the label–object pairings.

To examine whether the performance of the 22-month-olds was significantly different from the younger infants' performance in Experiment 1 (14- and 19-month-olds combined), we performed a 2 (experiment: Experiment 1 vs. Experiment 2; between subjects) × 2 (trial type: same vs. switch; within subjects) repeated measures ANOVA of infants' looking time. There were no main effects of experiment ($F < 1$) or trial type, $F(1, 46) = 2.52$, $p = .140$, $\eta_p^2 = .05$. However, there was a marginally significant Experiment × Trial Type interaction, $F(1, 46) = 3.77$, $p = .058$, $\eta_p^2 = .08$, suggesting that the bilingual 22-month-olds showed a weaker (*ns*) switch trial preference and weaker evidence of label learning than their younger bilingual peers.

General Discussion

We found that 14- and 19-month-old bilingual infants learned object labels that differed in a nonnative pitch contour contrast. They displayed flexibility in their interpretation of the types of sounds that act as words—young bilinguals treated distinct pitch contours as lexically contrastive even though they were not used contrastively in their own native languages. By 22 months of age, bilingual infants no longer displayed this flexibility. This pattern contrasts with the developmental trajectory of interpretive narrowing reported in previous research using the same methodology, in which monolingual English-learning 19-month-olds failed to learn labels with the same exact objects and pitch contours (Hay et al., 2015). Monolingual English-learning 14-month-olds succeeded in learning the labels, suggesting that accumulating experience with English led infants to restrict their interpretation of the sounds that can differentiate words in the middle of the 2nd year of life. Here, we present evidence that bilinguals show an extended period of flexibility in word learning. We suggest two hypotheses regarding why bilinguals maintain this interpretive flexibility.

First, bilinguals may maintain flexibility regarding possible word forms longer than monolinguals because they experience a protracted period of phonological development. They have two separate phonological systems to acquire, and hear less input in a given language than monolinguals do (Byers-Heinlein & Fennell, 2014; Costa & Sebastián-Gallés, 2014). The data are mixed regarding how bilingual experience affects the development of speech perception. Some experiments suggest that bilinguals have delays relative to monolinguals (Bosch & Sebastián-Gallés, 2003b; Ramon-Casas et al., 2009; Sebastián-Gallés & Bosch, 2009), whereas others do not (e.g., Burns et al., 2007; Sundara et al., 2008). The inconsistencies in the findings may be related to the languages and contrasts tested, as well as testing methodologies. When experimental tasks are designed to suit bilinguals' linguistic experiences, bilingual infants do not show delays relative to monolinguals (Albareda-Castellot et al., 2011; Mattock et al., 2010; see Sebastián-Gallés, 2011, for further discussion). Still, differences in performance across groups suggest that experience-driven language-specific speech perception may take longer to emerge for bilinguals than for monolinguals (Garcia-Sierra et al., 2011). Similarly, in word learning, bilinguals may entertain a broad range of options for how sounds make meaningful distinctions between words for a longer period than monolinguals do. Bilingual input contains greater variability in how words sound compared to monolinguals. Their two languages may divide up the acoustic-phonetic space differently, creating different phoneme boundaries and categories, as well as different phoneme combinations. Therefore, bilinguals have experience with a wide variety of ways that sounds can form words. Relative to monolinguals, phonological development in bilinguals may take longer to determine which sound variants differentiate words and which do not. Thus, in the present task, bilingual infants showed interpretive narrowing for pitch contour several months later than monolinguals.

A second hypothesis is broader in scope: Bilinguals may be more flexible than monolinguals in how they interpret linguistic input. In learning and processing two languages, bilinguals gain experience shifting their attention across the appropriate acoustic characteristics for detecting, recognizing, and comprehending words in each language. For example, infants learning Chinese and English must shift between a language that uses pitch contour to differentiate words and one that does not. French-English bilinguals must shift between English, which makes a phonemic distinction between θ and ð (as in "think" and "these," respectively) and French, which uses neither consonant. There is prior evidence that bilingual speech processing is exquisitely sensitive to the contexts in which phoneme contrasts are tested, even in infancy (Fennell & Byers-Heinlein, 2014; Mattock et al., 2010). Bilinguals may develop skills for shifting attention to the information that is relevant for processing a particular language when the input provides the necessary cues. These skills may apply broadly to novel linguistic input, not just to the infants' native languages. In the present experiment, the input indicated that pitch contour distinctions were important for differentiating words linked to objects. For 19-month-old monolingual infants, this experience was not sufficient to promote learning of the labels (Hay et al., 2015). At 19 months, bilingual infants may be able to use information present in the input to direct attention to what is meaningfully relevant in the moment. However, by 22 months, bilingual infants learning two nontonal languages develop constraints on tone processing. Their knowledge of how pitch is used in their languages is strong enough to override the cues that pitch is relevant in the current task. This does not mean that word learning is entirely unconstrained in younger bilinguals. For example, Fennell and Byers-Heinlein (2014) found that bilinguals were not more open than monolinguals to learning labels produced in accents that did not match their own language experience (i.e., bilinguals learned labels from bilingual-produced input, not monolingual-produced input). There may be further limits to their interpretive breadth. For example, we are testing whether the observed openness in bilingual word learning is limited to linguistic stimuli, or whether it applies to nonlinguistic sounds as well.

The idea that bilinguals have advantages over monolinguals in general perceptual and attentional processes has been supported in prior work. For example, bilingual infants can attend to visual cues in faces silently producing speech to differentiate between two languages, even when both languages are unfamiliar (Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). In contrast, monolinguals cannot. The perceptual and attentional characteristics of bilingual infants may reflect adaptations to their input (Costa & Sebastián-Gallés, 2014; Kovacs & Mehler, 2009). Perhaps protracted flexibility in word learning is another form of adaptation. Our proposal here is similar to Petitto et al.'s (2012) notion that bilingual experience produces increased demands on language processing, which effectively boosts the ability to analyze multiple dimensions of linguistic structure, "leaving open and agile linguistic processing in general" (p. 140).

One question that the present results raise is: Why do bilingual infants successfully learn labels that contrast in tones at ages that they have difficulty learning labels that contrast in native phonemes? Fennell et al. (2007) found that bilinguals failed to learn minimal pair–object labels at 17 months (but see Mattock et al., 2010, for alternative results). Monolinguals in the same task failed to learn the labels at 14 months, but succeeded at 17 months (Werker et al., 2002). For young monolinguals and for bilinguals, the difficulty may arise from determining which perceptible sound variants are relevant in their native languages. They may initially be over-inclusive regarding the interpretation of pitch contour contrasts, yet underattentive to small between-category phonetic differences. One possible contributing factor is the acoustic salience of the pitch contours that formed the tone contrast. The pitch contours unfolded over hundreds of milliseconds and moved across a wide frequency range. In comparison, the phonemes examined in similar experiments were typically stop consonants (Pater, Stager, & Werker, 2004; Werker et al., 2002), and thus differed in subtler characteristic than the tones, differing by only tens of milliseconds of voice onset time.

Furthermore, although neither of the bilingual infants' native languages used tone to contrast word meanings, pitch contour patterns are prevalent, salient, and significant in the infants' input. They are important for infants' interpretation of utterance boundaries and utterance types, as well as social information (Fernald, 1992; Seidl, 2007). Infants have substantial experience processing pitch and a great deal of input indicating that pitch is a crucial characteristic of the speech signal. The salience and significance of pitch are also likely to explain why 14-month-old monolinguals attend to tone contrasts during word learning in the Switch paradigm (Hay et al., 2015), but not nonlinguistic or noncommunicative sounds (MacKenzie et al., 2011). The present evidence indicates that bilinguals maintain this flexibility in their interpretation of pitch information for a longer period than monolinguals.

An additional consideration is that the different developmental patterns of monolingual and bilingual infants may not actually be due to bilingualism, as we have proposed. Rather, early interpretive narrowing could occur specifically in English learners and the infants in the present experiment could show relative flexibility in label learning because they are learning a language other than English. This explanation seems unlikely for two reasons. First, none of the infants in this experiment were exposed to tonal languages, so they had no prior experience with the contrastive use of pitch contours. For example, consider Spanish and French, which were the most common second languages in our sample. In Spanish, like in English, pitch is a component of lexical stress, and lexical stress patterns can differentiate between words (Beckman, Díaz-Campos, Tevis McGory, & Morgan, 2002). In French, stress is found at the phrase level, rather than the lexical level, and is realized through final lengthening with no increase in pitch or intensity (Vaissiere, 1991). However, in all three of these languages, pitch is part of the signal conveying information such as emphasis, emotional tone, speaking register, and sentence context (e.g., question vs. declarative statement). All of this information affects the interpretation of utterances, but does not provide information indicating that pitch contour differences alone should differentiate between words. Second, the infants were exposed to a wide range of languages. Generally, languages manipulate pitch in different ways, as evidenced by the differences between Spanish and French. Thus, it seems improbable that such a broad group of languages would have the same effect on label learning, namely, to support the acceptance of pitch contour as lexically contrastive. Rather, the observed developmental pattern seems to be due to the experience of becoming bilingual. Future research will be necessary to determine how general the observed effect is, given that there are many different forms that bilingualism can take. For example, it is not yet clear whether our effect is specific to infants who are simultaneously exposed to two languages, or whether it also occurs for sequential bilinguals.

Singh et al. (2014) also found evidence of interpretive narrowing in bilingual infants' treatment of pitch contour; they found that English monolinguals and nontonal language bilinguals showed the same developmental trajectory, whereas we found different developmental patterns across groups. Specifically, Singh et al. found that both monolingual and bilingual 18-month-olds detected changes in the pitch contours of new words. By 24 months, infants in both groups showed constraint in their interpretation of pitch and did not attend to pitch contour changes. In the present experiments, we found that bilinguals showed successful learning of labels that differed only in pitch contour at 14 and 19 months, but not at 22 months, whereas Hay et al. (2015) found that English monolinguals in the same task learned the labels at 14 months, but not at 19 months.

As discussed in the Introduction, we propose that the difference in findings for monolinguals' processing of pitch contour in the middle of the 2nd year arose primarily because of differences in the designs of the tasks used by Hay et al. (2015) versus Singh et al. (2014). Differences in task designs may also explain the patterns of bilinguals' performance across studies. Singh et al.'s (2014) task incorporated substantial referential support for word learning. The labels were presented in carrier phrases and infants viewed supplementary trials with familiar objects. Both of these characteristics have been shown to promote attention to detail in the sounds of words during label learning (Fennell & Waxman, 2010). In contrast, studies using the Switch paradigm (similar to the present experiments), without referential support, have demonstrated that 14-month-olds have difficulty attending to phonetic detail in new words (Pater et al., 2004; Stager & Werker, 1997). The apparently simple Switch task uncovered a vulnerability in processing phonetic detail that was not apparent in richer tasks.

The importance of task demands in revealing developmental patterns is supported in the PRIMIR model of infant speech perception and word learning (Curtin et al., 2011; Werker & Curtin, 2005; Yoshida, Fennell, Swingley, & Werker, 2009). For monolinguals, the differences in methodology across Hay et al.'s (2015) and Singh et al.'s (2014) studies revealed an unstable characteristic of infants' processing. In the middle of the 2nd year, the methods by which object labels are introduced and tested affects how infants direct attention to the sounds of the words. Referential information may free cognitive resources, allowing infants to attend more closely to the acoustic-phonetic details of new words. In Singh et al.'s task, the referential context may have promoted monolingual and bilingual 18-month-olds' attention to detail, even for a dimension of speech that is not used to differentiate word meanings in their native languages. Seventeen- to 19-month-old monolingual English-learning infants do not show this level of attention to pitch contour in tasks that lack referential support (Hay et al., 2015). Similarly, May and Werker (2014) found that monolingual 14-month-olds, as well as 20-month-olds with small vocabularies, learned labels containing non-native click contrasts in a referential context, but not without referential cues. Twenty-month-olds with larger vocabularies did not learn the labels in either context.

The present findings indicate that bilingual 19-month-olds do not require referential support to attend to pitch contour when learning new words. We propose that this indicates that for bilinguals around 18–19 months of age, attention to pitch contour in new words is robust; it occurs in both word learning tasks in which referential support is present and in tasks in which it is absent. By 22 months of age, bilinguals no longer show attention to pitch in the Switch paradigm when learning labels that differ only in pitch, and at 24 months they no longer show attention to pitch in the referential paradigm (Singh et al., 2014). Thus, by around age 2, knowledge of how pitch is used in bilinguals' native languages may lead to the development of firm constraints on how pitch is interpreted, constraints that are not readily perturbed by variation in learning and testing environments.

We expect that there is a convergence of factors that affect infants' acceptance of novel word forms, including the availability of referential cues, the details of the sound sequences, as well as the infant's experience and developmental level. For labels consisting of native sounds, the presence of referential information may promote earlier sensitivity to phoneme contrasts than without referential cues (Fennell & Waxman, 2010; Werker et al., 2002). For labels containing non-native sounds, referential information may also support greater attention to detail, including attention to sound contrasts that are not lexically contrastive in the native language(s). In the absence of referential cues, learning appears more constrained (Hay et al., 2015; May & Werker, 2014; Singh et al., 2014). In the present work, the absence of referential cues also revealed extended flexibility in label learning for bilingual infants. A key point that merits further attention is the generality of bilinguals' extended flexibility in label learning. We have proposed that infants maintain attention to pitch contour in labels because of its salience and prevalence in the input. It will be important to expand the investigation to other non-native sound contrasts varying in salience and degree of similarity to the native input. Some non-native contrasts may be so distant from native-language experience that infants do not readily entertain them as labels. Bilinguals may show a developmental progression similar to monolinguals in these cases, or they may be open to some types of sound contrasts that monolinguals are not open to. These ideas remain to be tested.

In conclusion, the current results indicate that bilingual infants are flexible in their interpretation of the sounds that make meaningful distinctions between words for a longer developmental period than monolinguals infants are. This flexibility seems to represent an appropriate strategy for bilingual infants. It fits with their phonological and lexical experience and the demands of their linguistic environments.

References

Albareda-Castellot, B., Pons, F., & Sebastián-Gallés, N. (2011). The acquisition of phonetic categories in bilingual infants: New data from an anticipatory eye movement paradigm. *Developmental Science*, *14*, 395–401. doi:10.1111/j.1467-7687.2010.00989.x

Beckman, M. E., Díaz-Campos, M., Tevis McGory, J., & Morgan, T. A. (2002). Intonation across Spanish, in the Tones and Break Indices framework. *Probus*, *14*, 9–36. doi:10.1515/prbs.2002.008

Bialystok, E., Barac, R., Blaye, A., & Poulin-Dubois, D. (2010). Word mapping and executive functioning in young monolingual and bilingual children. *Journal of Cognition and Development*, *11*, 485–508. doi:10.1080/15248372.2010.516420

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*, 859–873. doi:10.1037/0278-7393.34.4.859

Bosch, L., & Ramon-Casas, M. (2011). Variability in vowel production by bilingual speakers: Can input properties hinder the early stabilization of contrastive categories? *Journal of Phonetics*, *39*, 514–526. doi:10.1016/j.wocn.2011.02.001

Bosch, L., & Sebastián-Gallés, N. (2003a). *Language experience and the perception of a voicing contrast in fricatives: Infant and adult data*. Paper presented at the 15th International Congress of the Phonetic Sciences, Barcelona, Spain.

Bosch, L., & Sebastián-Gallés, N. (2003b). Simultaneous bilingualism and the perception of a language-specific vowel contrast in the first year of life. *Language and Speech*, *46*, 217–243. doi:10.1177/00238309030460020801

Burns, T. C., Yoshida, K. A., Hill, K., & Werker, J. F. (2007). The development of phonetic representation in bilingual and monolingual infants. *Applied Psycholinguistics*, *28*, 455–474. doi:10.1017/s0142716407070257

Byers-Heinlein, K. (2013). Parental language mixing: Its measurement and the relation of mixed input to young bilingual children's vocabulary size. *Bilingualism: Language and Cognition*, *16*, 32–48. doi:10.1017/S1366728912000120

Byers-Heinlein, K., & Fennell, C. T. (2014). Perceptual narrowing in the context of increased variation: Insights from bilingual infants. *Developmental Psychobiology*, *56*, 274–291. doi:10.1002/dev.21167

Byers-Heinlein, K., Fennell, C. T., & Werker, J. F. (2013). The development of associative word learning in monolingual and bilingual infants. *Bilingualism: Language and Cognition*, *16*, 198–205. doi:10.1017/S1366728912000417

Byers-Heinlein, K., & Werker, J. F. (2013). Lexicon structure and the disambiguation of novel words: Evidence from bilingual infants. *Cognition*, *128*, 407–416. doi:10.1016/j.cognition.2013.05.010

Cohen, L. B., Atkinson, D. J., & Chaput, H. J. (2004). *Habit X: A new program for obtaining and organizing data in infant perception and cognition studies (Version 1.0)*. Austin: University of Texas.

Costa, A., & Sebastián-Gallés, N. (2014). How does the bilingual experience sculpt the brain? *Nature Reviews Neuroscience*, *15*, 336–345. doi:10.1038/nrn3709

Curtin, S., Byers-Heinlein, K., & Werker, J. F. (2011). Bilingual beginnings as a lens for theory development: PRIMIR in focus. *Journal of Phonetics*, *39*, 492–504. doi:10.1016/j.wocn.2010.12.002

Dryer, M. S., & Haspelmath, M. (2011). *Word atlas of language structures*. Munich, Germany: Max Planck Digital Library. Retrieved from http://wals.info/

Fennell, C. T., & Byers-Heinlein, K. (2014). You sound like mommy: Bilingual and monolingual infants learn words best from speakers typical of their language environments. *International Journal of Behavioral Development*, *38*, 309–316. doi:10.1177/0165025414530631

Fennell, C. T., Byers-Heinlein, K., & Werker, J. F. (2007). Using speech sounds to guide word learning: The case of bilingual infants. *Child Development*, *78*, 1510–1525. doi:10.1111/j.1467-8624.2007.01080.x

Fennell, C. T., & Waxman, S. R. (2010). What paradox? Referential cues allow for infant use of phonetic detail in word learning. *Child Development*, *81*, 1376–1383. doi:10.1111/j.1467-8624.2010.01479.x

Fernald, A. (1992). Human maternal vocalizations to infants as biologically relevant signals: An evolutionary perspective. In J. H. Barkow, L. Cosmides, & J. Tooby (Eds.), *The adapted mind: Evolutionary psychology and the generation of culture* (pp. 391–428). New York, NY: Oxford University Press.

Fry, D. B. (1958). Experiments in the perception of stress. *Language and Speech*, *1*, 126–152. doi:10.1177/002383095800100207

Garcia-Sierra, A., Rivera-Gaxiola, M., Percaccio, C. R., Conboy, B. T., Romo, H., Klarman, L., . . . Kuhl, P. K. (2011). Bilingual language learning: An ERP study relating early brain responses to speech, language input, and later word production. *Journal of Phonetics*, *39*, 546–557. doi:10.1016/j.wocn.2011.07.002

Graf Estes, K., & Bowen, S. (2013). Learning about sounds contributes to learning about words: Effects of prosody and phonotactics on infant word learning. *Journal of Experimental Child Psychology*, *114*, 405–417. doi:10.1016/j.jecp.2012.10.002

Graf Estes, K., Edwards, J., & Saffran, J. R. (2011). Phonotactic constraints on infant word learning. *Infancy*, *16*, 180–197. doi:10.1111/j.1532-7078.2010.00046.x

Graf Estes, K., Evans, J. L., Alibali, M. W., & Saffran, J. R. (2007). Can infants map meaning to newly segmented words? Statistical segmentation and word learning. *Psychological Science*, *18*, 254–260. doi:10.1111/j.1467-9280.2007.01885.x

Grosjean, F. (2010). *Bilingualism: Life and reality*. Cambridge, MA: Harvard University Press.

Gussenhoven, C. (2004). *The phonology of tone and intonation*. Cambridge, UK: Cambridge University Press.

Hay, J. F., Graf Estes, K., Wang, T., & Saffran, J. R. (2015). From flexibility to constraint: The contrastive use of lexical tone in early word learning. *Child Development*, *86*, 10–22. doi:10.1111/cdev.12269

Hay, J. F., Pelucchi, B., Graf Estes, K., & Saffran, J. R. (2011). Linking sounds to meanings: Infant statistical learning in a natural language. *Cognitive Psychology*, *63*, 93–106. doi:10.1016/j.cogpsych.2011.06.002

Hoff, E., Core, C., Place, S., Rumiche, R., Señor, M., & Parra, M. (2012). Dual language exposure and early bilingual development. *Journal of Child Language*, *39*, 1–27. doi:10.1017/S0305000910000759

Kovacs, Å. M., & Mehler, J. (2009). Cognitive gains in 7-month-old bilingual infants. *Proceedings of the National Academy of Sciences of the United States of America*, *106*, 6556–6560. doi:10.1073/pnas.0811323106

Kuhl, P. K., Stevens, E., Hayashi, A., Deguchi, T., Kiritani, S., & Iverson, P. (2006). Infants show a facilitation effect for native language phonetic perception between 6 and

12 months. *Developmental Science*, *9*, F13–F21. doi:10.1111/j.1467-7687.2006.00468.x

MacKenzie, H., Graham, S. A., & Curtin, S. (2011). 12-month-olds priviledge words over other linguistic sounds in an associative learning task. *Developmental Science*, *14*, 249–255. doi:10.1111/j.1467-8624.2012.01764.x

Mattock, K., & Burnham, D. (2006). Chinese and English infants' tone perception: Evidence for perceptual reorganization. *Infancy*, *10*, 241–265. doi:10.1207/s15327078in1003_3

Mattock, K., Molnar, M., Polka, L., & Burnham, D. (2008). The developmental course of lexical tone perception in the first year of life. *Cognition*, *106*, 1367–1381. doi:10.1016/j.cognition.2007.07.002

Mattock, K., Polka, L., Rvachew, S., & Krehm, M. (2010). The first steps in word learning are easier when the shoes fit: Comparing monolingual and bilingual infants. *Developmental Science*, *13*, 229–243. doi:10.1111/j.1467-7687.2009.00891.x

May, L., & Werker, J. F. (2014). Can a click be a word? Infants' learning of non-native words. *Infancy*, *19*, 281–300. doi:10.1111/infa.12048

Murray, I. R., & Arnott, J. L. (1993). Toward the simulation of emotion in synthetic speech: A review of the literature on human vocal emotion. *Journal of the Acoustical Society of America*, *93*, 1097–1108. doi:10.1121/1.405558

Namy, L. L. (2001). What's in a name when it isn't a word? 17-month-olds' mapping of nonverbal symbols to object categories. *Infancy*, *2*, 73–86. doi:10.1207/S15327078IN0201_5

Oller, D. K., Eilers, R. E., Urbano, R., & Cobo-Lewis, A. B. (1997). Development of precursors to speech in infants exposed to two languages. *Journal of Child Language*, *24*, 407–425. doi:10.1017/S0305000997003097

Pater, J., Stager, C. L., & Werker, J. F. (2004). The lexical acquisition of phonological contrasts. *Language*, *80*, 361–379. doi:10.1353/lan.2004.0141

Pearson, B. Z., Fernandez, S. C., & Oller, D. K. (1993). Lexical development in bilingual infants and toddlers: Comparison to monolingual norms. *Language Learning*, *43*, 93–120. doi:10.1111/j.1467-1770.1993.tb00174.x

Petitto, L. A., Berens, M. S., Kovelman, I., Dubins, M. H., Jasinska, K., & Shalinsky, M. (2012). The "perceptual wedge hypothesis" as the basis for bilingual babies' phonetic processing advantage: New insights from fNIRS brain imaging. *Brain and Language*, *121*, 130–143. doi:10.1016/j.bandl.2011.05.003

Petitto, L. A., Katerelos, M., Levy, B. G., Gauna, K., Tétreault, K., & Ferraro, V. (2001). Bilingual signed and spoken language acquisition from birth: Implications for the mechanisms underlying early bilingual language acquisition. *Journal of Child Language*, *28*, 453–496. doi:10.1017/S0305000901004718

Poulin-Dubois, D., Blaye, A., Coutya, J., & Bialystok, E. (2011). The effects of bilingualism on toddlers' executive functioning. *Journal of Experimental Child Psychology*, *108*, 567–579. doi:10.1016/j.jecp.2010.10.009

Ramon-Casas, M., Swingley, D., Sebastián-Gallés, N., & Bosch, L. (2009). Vowel categorization during word recognition in bilingual toddlers. *Cognitive Psychology*, *59*, 96–121. doi:10.1016/j.cogpsych.2009.02.002

Rivera-Gaxiola, M., Silva-Pereyra, J., & Kuhl, P. K. (2005). Brain potentials to native and non-native speech contrasts in 7- and 11-month-old American infants. *Developmental Science*, *8*, 162–172. doi:10.1111/j.1467-7687.2005.00403.x

Scott, L. S., Pascalis, O., & Nelson, C. A. (2007). A domain-general theory of the development of perceptual discrimination. *Current Directions in Psychological Science*, *16*, 197–201. doi:10.1111/j.1467-8721.2007.00503.x

Sebastián-Gallés, N. (2011). Bilingual language acquisition: Where does the difference lie? *Human Development*, *53*, 245–255. doi:10.1159/000321282

Sebastián-Gallés, N., Albareda-Castellot, B., Weikum, W. M., & Werker, J. F. (2012). A bilingual advantage in visual language discrimination in infancy. *Psychological Science*, *23*, 994–999. doi:10.1177/0956797612436817

Sebastián-Gallés, N., & Bosch, L. (2009). Developmental shift in the discrimination of vowel contrasts in bilingual infants: Is the distributional account all there is to it? *Developmental Science*, *12*, 874–887. doi:10.1111/j.1467-7687.2009.00829.x

Seidl, A. (2007). Infants' use and weighting of prosodic cues in clause segmentation. *Journal of Memory and Language*, *57*, 24–48. doi:10.1016/j.jml.2006.10.004

Singh, L., Hui, T. J., Chan, C., & Golinkoff, R. M. (2014). Influences of vowel and tone variation on emergent word knowledge: A cross-linguistic investigation. *Developmental Science*, *17*, 94–109. doi:10.1111/desc.12097

So, C. K., & Best, C. T. (2010). Cross-language perception of non-native tonal contrasts: Effects of native phonological and phonetic influences. *Language and Speech*, *53*, 273–293. doi:10.1177/0023830909357156

Stager, C. L., & Werker, J. F. (1997). Infants listen for more phonetic detail in speech perception than in word-learning tasks. *Nature*, *388*, 381–382. doi:10.1038/41102

Sundara, M., Polka, L., & Baum, S. (2006). Production of coronal stops by simultaneous bilingual adults. *Bilingualism: Language and Cognition*, *9*, 97–114. doi:10.1017/S1366728905002403

Sundara, M., Polka, L., & Molnar, M. (2008). Development of coronal stop perception: Bilingual infants keep pace with their monolingual peers. *Cognition*, *108*, 232–242. doi:10.1016/j.cognition.2007.12.013

Vaissiere, J. (1991). Rhythm, accentuation and final lengthening in French. In J. Sundberg, L. Nord, & R. Carlson (Eds.), *Music, language, speech and brain* (Vol. 59, pp. 108–120). Basinstoke, UK: Macmillan.

Werker, J. F., Cohen, L. B., Lloyd, V. L., Casasola, M., & Stager, C. L. (1998). Acquisition of word-object associations by 14-month-old infants. *Developmental*

Psychology, *34*, 1289–1309. doi:10.1037/0012-1649.34.6.1289

Werker, J. F., & Curtin, S. (2005). PRIMIR: A developmental framework of infant speech processing. *Language Learning and Development*, *1*, 197–234. doi:10.1207/s15473341lld0102_4

Werker, J. F., Fennell, C. T., Corcoran, K. M., & Stager, C. L. (2002). Infants' ability to learn phonetically similar words: Effects of age and vocabulary size. *Infancy*, *3*, 1–30. doi:10.1207/15250000252828226

Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development*, *7*, 49–63. doi:10.1016/s0163-6383(84)80022-3

Woodward, A. L., & Hoyne, K. L. (1999). Infants' learning about words and sounds in relation to objects. *Child Development*, *70*, 65–77. doi:10.1111/1467-8624.00006

Yeung, H. H., Chen, K. H., & Werker, J. F. (2013). When does native language input affect phonetic perception? The precocious case of lexical tone. *Journal of Memory and Language*, *68*, 123–139. doi:10.1016/j.jml.2012.09.004

Yip, M. (2002). *Tone*. Cambridge, UK: Cambridge University Press.

Yoshida, K. A., Fennell, C. T., Swingley, D., & Werker, J. F. (2009). Fourteen-month-old infants learn similar-sounding words. *Developmental Science*, *12*, 412–418. doi:10.1111/j.1467-7687.2008.00789.x