

## Novel Word Learning in Bilingual and Monolingual Infants: Evidence for a Bilingual Advantage

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Previous studies revealing that monolingual and bilingual infants learn similar sounding words with comparable success are largely based on prior investigations involving single-feature changes in the onset consonant of a word. There have been no investigations of bilingual infants' abilities to learn similar sounding words differentiated by vowels. In the current study, 18-month-old bilingual and monolingual infants ( $n = 90$ ) were compared on their sensitivity to a vowel change when learning the meanings of words. Bilingual infants learned similar sounding words differing by a vowel contrast, whereas monolingual English- and Mandarin-learning infants did not. Findings are discussed in terms of early constraints on novel word learning in bilingual and monolingual infants.

Most children are raised with more than one native language (Grosjean, 1989), and in increasing measure, researchers have begun to direct their empirical efforts toward the multilingual child. A fundamental question often posed by parents of multilingual children, educators, and researchers alike is whether bilingual learners demonstrate delays or differences in their pathway to language proficiency on account of having to master two languages. One way to answer this question is to compare bilingual and monolingual learners on standardized measures of formal language skills, such as vocabulary size. Such comparisons have resulted in a mixed narrative (e.g., De Houwer, Bornstein, & Putnick, 2014; Bialystok, Luk, Peets, & Yang, 2010; De Houwer, Bornstein, & Putnick, 2014; Hoff et al., 2012; Pearson, Fernández, & Oller, 1993). This is perhaps in part due to the wide range of factors that appear to influence the outcome of these comparisons, such as socioeconomic variation, the language of testing in relation to participants' language backgrounds, the specific calculation used

to estimate vocabulary size, among other factors. However, a complementary approach to this question is to compare monolinguals and bilinguals on the facility with which they add new words to their vocabularies (Fennell & Byers-Heinlein, 2014; Fennell, Byers-Heinlein, & Werker, 2007; Mattock, Polka, Rvachew, & Krehm, 2010). These studies suggest that bilingual and monolingual infants resemble each other when provided with bilingual and monolingual input, respectively. Thus far, the conclusions from these studies are based on measures of sensitivity to one source of phonetic variation, specifically, variation in single-feature changes in the initial consonant of a word (such as a change from "bih" to "dih"). However, in human languages, words are variously differentiated by sources of phonetic change, such as changes in vowels (e.g., a change from "bet" to "bat") and in lexical tone (as in languages such as Mandarin Chinese, Vietnamese, or Thai). The goal of the current study is to investigate the process by which monolinguals and bilinguals master similar sounding words that vary in alternative segments, specifically, in vowel quality.

A crucial component of language acquisition is the ability to rapidly link sound and meaning. This process, termed associative word learning, is thought to initiate and catalyze the growth of a

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native vocabulary (Mayor & Plunkett, 2010; Smith, Jones, Yoshida, & Colunga, 2003). The capacity for associative word learning has been well documented in infants, who demonstrate an impressive facility in establishing new word–object associations with surprisingly little exposure (e.g., Stager & Werker, 1997; Werker, Cohen, Lloyd, Casasola, & Stager, 1998). Investigations of associative word learning have employed a variety of paradigms, including the *switch* paradigm of direct relevance to the present study (Werker et al., 1998). In this paradigm, infants are typically exposed to two novel objects, each presented in conjunction with a different verbal label during a learning phase. After repeated exposure to word–object pairings, infants’ attention levels customarily wane and decline to a preset attentional criterion. At this point, a test phase is initiated. During the test phase, infants view one of the objects encountered during the familiarization phase correctly labeled (the “same” trial). They also view the other object encountered during the familiarization phase, but this object is incorrectly labeled with the name for the other familiarization object (the “switch” trial). Evidence of having encoded the word–object pairings taught during familiarization usually involves a “surprise” response, expressed by an elevation in looking times to the object that is mislabeled versus the one that is correctly labeled.

Using the switch paradigm to determine the level of phonological precision with which infants represent words as they gradually expand their nascent vocabularies, Stager and Werker (1997) demonstrated that at 14 months of age, infants were not able to link similar sounding novel words with novel objects. However, the same study revealed that these phonetic contrasts were discriminated several months earlier in a discrimination paradigm that did not entail word–object mapping. It should be noted that infants’ sensitivity to mispronunciations appears to be highly dependent on the task used to measure phonological sensitivity. Of particular relevance to the present study are previous studies focusing on effects of phonological variation on infants’ abilities to learn new words, which is distinct from a separate literature on effects of phonological variation in recognition of familiar words. In novel word learning, other paradigms, such as preferential looking, name-based categorization, habituation/preferential looking combinations, and head-turn preference paradigms, have revealed evidence for early sensitivity to mispronunciations arising from vowel changes and from consonant changes (e.g., Mani & Plunkett,

2008; Nazzi, Floccia, Moquet, & Butler, 2009; Nazzi & New, 2007; Yoshida, Fennell, Swingley, & Werker, 2009). Nevertheless, the switch paradigm offers a high degree of control over experimental parameters, is an effective means by which to investigate constraints on word learning in infancy, and as a consequence, has been widely and productively used to investigate constraints on early word learning in infancy. Our decision to employ the switch paradigm was based on the wealth of previous studies that have used this paradigm to investigate phonological specificity in novel word learning in infancy (particularly in bilingual populations). This affords comparison of our findings with prior studies and allows us to situate our findings within proximate literature.

Further research has corroborated the finding that similar sounding words are particularly difficult for infants to map to meanings at 14 months of age (Pater, Stager, & Werker, 2004) and that this ability emerges stably later only at 17 months of age (Werker, Fennell, Corcoran, & Stager, 2002; but see Fennell & Waxman, 2010). In a comparison of monolingual and bilingual infants on their ability to learn similar sounding words via the switch task, Fennell et al. (2007) demonstrated that 17-month-old bilingual infants appeared less sensitive than monolingual infants to subtle differences in the initial consonant of a word when learning novel words. This appears not to be due to constraints on forming word–object associations as bilingual infants could learn *dissimilar* sounding words as effectively as monolingual infants at 14 months (Byers-Heinlein, Fennell, & Werker, 2013). Conclusions drawn from Fennell et al. (2007) about a bilingual delay in learning similar sounding words have since been modified in further studies by Fennell and Byers-Heinlein and Mattock and colleagues. In a series of related studies designed to further investigate word learning in bilingual infants, these researchers probed bilinguals’ ability to learn similar sounding words in relation to the structure of language input provided in the task. In one study, Mattock et al. (2010) presented bilingual infants with tokens drawn from both of their languages. Mattock et al. demonstrated that when phonetic properties of words accorded with the phonological inventories of both native languages the bilingual child was acquiring—and not just one of their languages—bilinguals linked similar sounding words to their meanings at 17 months (Mattock et al., 2010). Likewise, bilinguals learned novel words when they were given explicit cues to language identity prior to the presentation of the words to be

learned (Fennell & Byers-Heinlein, 2011). Most recently, Fennell and Byers-Heinlein (2014) demonstrated that bilingual and monolingual infants at 17–18 months are sensitive to subtle phonetic detail associated with newly learned words. Both monolingual and bilingual infants were sensitive to phonetic variation in the onset consonant of newly learned words only when the speaker matched their language background (i.e., when the speaker was monolingual or bilingual, respectively). Although monolingual and bilingual infants appear to proceed in lock step with regard to phonological sensitivity to consonants (as long as the input is aligned with their language environment), a recent study suggests that group differences are apparent when other phonological constituents are considered. Using the switch paradigm, Singh, Poh, and Fu (2016) tested monolingual Mandarin and bilingual Mandarin–English learners on their ability to integrate lexical tones when learning new words embedded in Mandarin carrier sentences. Their study revealed that bilingual infants at 12–13 months were able to integrate both salient and subtle tone contrast into newly learned words; by contrast, Mandarin monolingual infants did not integrate either type of tone contrast into newly learned words until 18 months. These findings point to the fact that different phonological constituents can elicit different effects of bilingualism on novel word learning, providing an impetus to investigate effects of bilingualism on vowel sensitivities.

In combination, recent studies investigating bilingual infants' ability to learn similar sounding words suggest that they are indeed comparable to monolingual infants with respect to consonant variation. Specifically, both groups of infants appear to be particularly vulnerable to the phonetic overlap between the words to be learned and their ambient language input (e.g., Fennell & Byers-Heinlein, 2014). Specifically, when tasked with mapping minimal pairs distinguished by consonant variation onto different meanings, word learning in both groups is enabled by speech input that matches their language environment. These findings imply that monolingual and bilingual infants resemble one another to a greater extent than originally thought (e.g., Fennell et al., 2007) and, arguably, that both groups maintain perceptual sensitivities that are keenly optimized for their language environments. In contrast, with respect to lexical tones, even when language input matches their linguistic background, bilinguals demonstrate precocious integration of tones

compared to monolingual tone language learners (Singh et al., 2016).

Prior research has relied heavily on assessing infants' sensitivity to consonant contrasts in novel word learning. In contrast, there has been relatively little research on mastery of similar sounding words defined by vowel contrasts. The notion that vowels and consonants may impact early word learning in different ways has been investigated quite extensively in monolingual learners. In infants and toddlers, several studies have revealed differential sensitivity to vowels and consonants in spoken word recognition (Havy & Nazzi, 2009; Nazzi, 2005; Nazzi et al., 2009; but also see Floccia, Nazzi, Delle Luche, Poltrock, & Goslin, 2014; Mani & Plunkett, 2008, 2010). Although infants' abilities to map vowel contrasts onto words have not been investigated in bilinguals, two studies in this vein have been conducted with monolinguals. In one study, Curtin, Fennell, and Escudero (2009) employed the switch paradigm to investigate mapping of similar sounding words contrasting a single-feature versus two-feature vowel contrast in 15-month-old monolingual infants. Curtin et al. reported vowel-specific effects: A single-feature change in vowel height was detected by infants at 15 months and mapped discretely onto separate objects, whereas a two-feature change in backness and roundedness was not mapped onto different objects at the same age. In a similar study, Dietrich, Swingley, and Werker (2004) investigated mastery of word–object mappings when words differed in a single feature—vowel length—in 18-month-old infants. They compared participants for whom the contrast was phonemic in their native language with participants for whom the contrast was not phonemic. Infants successfully mapped vowel-contrastive forms onto different meanings if the vowel contrast was phonemic in their native lexicon but failed to do so if it was not. These findings suggest that responses to subtle change in associative learning are rooted in native phonology by 18 months and not in basic perceptual acuity for acoustic–phonetic change. Taken together, prior investigations of phonological sensitivity using the switch paradigm suggests that different phonetic contrasts evince different results and that for monolingual infants, the level of phonological sensitivity in novel word learning is not the same for different type of phonemes (from vowels to consonants, for example). Vowels and consonants may also result in different levels of sensitivity for bilingual learners; as a result,

prior studies investigating sensitivity to mispronunciations caused by consonant variation may not generalize to vowel variation.

A crucial question commonly applied to previously attested developmental milestones is the extent to which they generalize to the larger population. This question is invited by prior studies on mispronunciation sensitivity in bilingual learners for two reasons. First, conclusions drawn from prior studies have relied heavily on mispronunciation sensitivity to consonant contrasts, and it remains to be seen whether similar results would be obtained with other types of phonemic variation, such as vowels. Second, conclusions drawn from prior studies have relied on evidence from speakers of a particular class of languages, namely intonation (or nontone) languages. Can we generalize from consonants to vowels? Also can we generalize from speakers of English to speakers of other commonly spoken languages, such as Mandarin Chinese and furthermore, to bilingual speakers? Each of these questions will be discussed in turn.

First, there are strong empirical and theoretical grounds on which to predict that sensitivity to vowels and consonants differs in early word recognition and word learning. In studies with infants and toddlers, several studies have demonstrated differential sensitivity to vowels and consonants in spoken word recognition (Havy & Nazzi, 2009; Havy, Serres, & Nazzi, 2013; Nazzi, 2005; Nazzi et al., 2009; but see also Floccia et al., 2014; Mani & Plunkett, 2008). Vowels and consonants are associated with discrete processing both at a functional level, assuming prominence at different tiers of the speech code, with vowels more closely tied to melody and consonants more closely tied to speech (e.g., Kolinsky, Lidji, Peretz, Besson, & Morais, 2009). Similarly, consonant variation is reportedly more conducive to the abstraction of statistical regularities than vowel variation (e.g., Bonatti, Peña, Nespor, & Mehler, 2005), suggesting vowels and consonants may play different roles in the developmental uptake of linguistic structure. With regard to neural representation, vowels and consonants are also reportedly to be neurolinguistically separable and linked to distinct neural regions (e.g., Caramazza, Chialant, Capasso, & Miceli, 2000) with neurophysiological responses for vowels and consonants associated with discrete temporal processing windows (Carreiras, Gillon-Dowens, Vergara, & Perea, 2009). Finally, consonant/vowel asymmetries appear to extend to the written word (Acha & Perea, 2010; New, Araújo, & Nazzi, 2008; New & Nazzi, 2014). In sum, across a broad swath of

domains, there is a broad basis of evidence to suggest that consonantal processing is fundamentally different to vocalic processing across the life span. These differences invite the possibility that prior conclusions on the bilingual phonological lexicon drawn from consonant sensitivity may not readily extend to vowels. A formal articulation of the phonological lexicon would ideally draw evidence from both vowels and consonants (and although not directly relevant to the present study, also from lexical tones) in order to establish a comprehensive profile of the structure of the emergent lexicon. A systematic investigation of the effects of vowel variation on word learning can potentially inform our interpretation of prior findings to determine whether previously reported trajectories are limited to stop consonants or whether they extend across the phonological inventory.

Second, prior conclusions on the bilingual phonological lexicon have relied predominantly on evidence from learners of languages such as English, often classified as “intonation languages.” In large part, these conclusions have been interpreted as reflecting language-general constraints on the emergent lexicon in spite of drawing from a subset of human languages. In fact, most of the world speaks a tone language (Yip, 2002). This distinction is significant when evaluating sensitivity to phonemic contrast. The phonological constraints on tone languages appear to differ from those on intonation languages. Relevant to the present study, it is widely acknowledged that consonants bear a heavier lexical load in intonation languages such as English or French (Nespor, Peña, & Mehler, 2003). Until recently, a consonant bias was thought to apply universally. However, recent studies suggest that tone languages, in particular, Mandarin Chinese are structured very differently: Vowels bear a heavier lexical load than consonants (see Chen, Wong, Zhu, & Wong, 2015; Wiener & Turnbull, 2016). Given that the most widely spoken language in the world is Mandarin Chinese, this suggests that the consonant bias thought to constrain the developing phonological lexicon may not apply to the majority of language learners. It should be noted that a vowel bias is not limited to tone languages but is also evident in nontone languages where vowels overwhelm consonants in set size and salience (see Højen & Nazzi, 2016). On account of cross-linguistic evidence that constraints on the early phonological lexicon vary across languages, it is potentially productive to test sensitivity to the same contrast across learners of different language backgrounds. Current theories of phonological development should optimally

draw from the full range of variation manifest in human languages in order to determine the extent to which findings apply universally or whether they are limited to a subset of the population. Given that Mandarin Chinese and English are two of the most widely spoken human languages, if phonological sensitivities fundamentally vary across these groups, this has implications for the extent to which extant findings drawn largely from English-learning infants reveal population-level development. Similarly, the generalizability of existing findings to bilingual learners necessarily circumscribes our interpretation of past studies. Although some studies that have manipulated consonant onsets have revealed parity across monolinguals and bilinguals in their phonological sensitivities, other studies that have investigated less common studied phonological constituents—such as Mandarin lexical tones—have revealed a bilingual advantage in phonological sensitivity to newly learned words (Singh et al., 2016). It therefore appears that studying different phonological constituents as well as different language backgrounds reveal varying effects of language background on phonological sensitivity. Different findings on effects of bilingualism on consonant versus tone sensitivity invites a comparison study of vowel sensitivity in novel word learning, which is an important gap in our understanding of phonological specification of words in monolinguals versus bilinguals. Given that Mandarin and English languages place different types of emphasis on vowels in the lexicon, the present study sampled from two types of monolinguals (English and Mandarin) and English–Mandarin bilingual learners in order to determine interactions of language background and phonological sensitivity.

In a set of three experiments, we compared mastery of similar sounding words in monolingual and bilingual infants when words were differentiated by vowel quality. Data were collected between February 2014 and September 2016. Our overarching goal was to determine how monolingual and bilingual infants might compare in their ability to learn similar sounding words and, furthermore, to elucidate conditions that may have contributed to differences in performance between groups. In Experiment 1, monolingual English and bilingual (English–Mandarin) infants were trained on two similar sounding words differing on account of their vowels produced by a monolingual English and bilingual English–Mandarin speaker, respectively. Infants were tested on recognition of these words when the labels were correctly pronounced and when they were mispronounced with a vowel substitution. In

Experiment 2, Mandarin-learning monolingual infants were tested on the same vowel contrast, produced by a monolingual Mandarin speaker, in order to qualify that findings obtained from Experiment 1 were not attributable to having native exposure to Mandarin. In Experiment 3, monolingual English-learning infants were presented with vowel contrastive forms produced by a bilingual speaker to determine whether bilingual input could potentially enhance sensitivity to vowel variation.

### Experiment 1

Using the switch paradigm, sensitivity to vowel contrasts that distinguished similar sounding words were compared across monolingual and bilingual infants. Infants were presented with stimuli that accorded with their language background as in prior studies (i.e., bilingual infants were presented with auditory stimuli produced by a bilingual speaker, and monolingual infants were presented with auditory stimuli produced by a monolingual speaker of the same language background).

#### *Method*

##### *Participants*

Forty-eight infants, ranging in age from 17 months 0 days to 18 months 3 days, participated (25 female) in this study. Twenty-four infants were monolingual English-learning infants, and 24 infants were bilingual learners of English and Mandarin. All infants were typically developing, full-term infants with no known developmental disorders or delays. Participants were selected based on their responses to a Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 1997). Infants were classified as monolingual if they were exposed to English at least 90% of the time. Data from three additional infants were discarded due to crying and failure to complete the testing session. Infants were classified as bilingual if they were exposed to two languages and received exposure of at least 30% of the time to one of those two languages. Monolingual infants were reared in a predominantly monolingual society and bilingual infants were raised in a society that was predominantly bilingual.

##### *Stimuli*

All tokens were recorded in a sound attenuated booth. Stimuli for the monolingual English sample

were recorded by a monolingual female English speaker, stimuli for the monolingual Mandarin sample were recorded by a monolingual female Mandarin speaker, and stimuli for the bilingual sample were recorded by a bilingual female English–Mandarin speaker in light of previous research demonstrating that infants learn words optimally when they are produced by a speaker of the same language background (Fennell & Byers-Heinlein, 2014; Mattock et al., 2010). Each speaker was asked to produce the tokens in an infant-directed manner. The auditory stimuli that served as object labels were “mIn” and “mən.” An additional pair of stimuli were recorded for pre- and posttest stimuli. These stimuli were recorded by a different female speaker and consisted of the words /pi/ and /pa/.

The auditory stimuli consisted of the syllables “mIn,” with a high front unrounded vowel, and “mən,” with a low central unrounded vowel. Acoustic analyses were conducted to capture differences in vowel quality across monolingual and bilingual speakers. Analyses focused on the first two formants (F1 and F2) as F1 relates to vowel height and F2 relates closely to backness, the two dimensions contrasted in our stimuli (Ladefoged, 2006). Productions of “mIn” were associated with distinct F1 and F2 profiles across both speakers. In particular, in the monolingual productions of “mIn,” the vowel was slightly lower and produced slightly further back than the bilingual productions, resembling the vowel in the English “bin.” The F1 and F2 values for this speaker were within the range of values reported for monolingual English speakers (Hillenbrand, Getty, Clark, & Wheeler, 1995). The same vowel produced by the bilingual speaker was higher and slightly fronted, resembling a vowel in between the English words “bin” and “been.” The vowel /I/ when produced by the bilingual speaker therefore had higher F2 values and lower F1 values than the same vowel produced by the monolingual speaker. The second vowel (in the target word “mən”) was less vulnerable to the effects of speaker background: The vowel in the English monolingual productions of “mən” corresponded closely to the low central unrounded vowel /ə/, approximating F1 and F2 values reported for English monolingual speakers (Hillenbrand et al., 1995). The first and second formants overlapped considerably for the monolingual and bilingual speaker for this vowel. In sum, there were subphonetic differences in the realizations of the vowel contrast between the monolingual and bilingual speakers. However, speaker differences were

most pronounced in the vowel /I/ suggesting that vowel quality for this vowel varied across the bilingual and monolingual speaker.

Three novel colorful objects were used as visual stimuli. Two images served as referents for the labels children were taught during training, and one of these images served as pre- and posttest stimuli. Images were whole objects that were designed to be distinct from one another. All three images were programmed to move at equal speed in a circular manner at the center of the screen against a white background. Between trials, an image of a looming blue and white ball against a black background was used to draw attention to the display screen. The assignment of word to object and the assignment of objects to the test phase were counterbalanced across subjects. A trial sequence can be viewed in Figure 1.

#### *Apparatus and Procedure*

Participants were tested using the switch paradigm developed by Werker et al. (1998). The paradigm was administered using Habit X 1.0 (University of Texas, Austin, TX) on a Macintosh computer. Infants were seated in their caregivers’ laps during the testing session approximately 70 cm from a 15-in. computer monitor. After being seated, the experimenter and caregiver listened to instrumental music over headphones at a level to mask the auditory stimuli. The session was initiated by an attention getter that flashed on the screen to recruit the infant’s attention. The experimenter could see the infants’ eyes through a closed-circuit TV system.

Upon fixation, a pretest trial was presented on screen for as long as the infant fixated the pretest stimulus. The pretest stimulus consisted of a colorful object accompanied by the sound /pi/. Following the pretest trial, the habituation phase was initiated. During this phase, infants viewed a moving object (Object A) on screen paired with an auditory stimulus (Word A) on some trials and with a second moving object (Object B) on screen paired with another auditory stimulus (Word B) on other trials. The label for one object was /mIn/ and for the other object was /mən/, and they were therefore distinguished only by the word-medial vowel. Word–object pairings were presented in blocks of four. Within a block, each pairing was repeated twice resulting in six different orders of pairings within each block (AABB, BBAA, ABAB, BABA, ABBA, BAAB). The order of presentation of blocks was randomized. Each habituation trial was terminated when infants looked away from the monitor

	Pre-test	Habituation Stimuli		Switch Trial	Same Trial	Post-test
Auditory Label	“pi”	“min”	“mun”	“min”	“mun”	“pi”
Visual Referent						

Figure 1. Composition of familiarization, same and switch test trials (Experiment 1). [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

screen a minimum of 2 s or when infants fixated their gaze to the screen for a maximum of 20 s. Presentation of the habituation trials continued until either of the following criteria were met: a decline in fixation to 50% of the average look time on the longest three trials or completion of 20 habituation trials. At this point, the test phase was initiated and consisted of two trials, a “switch” trial (e.g., Word A paired with Object B) and a “same” trial (e.g., Word B paired with Object B). The order of same/switch trials was counterbalanced across infants. Fixation times were logged by computer to each test trial. Finally, a posttest trial was presented, consisting of the same auditory–visual pairing as the pretest trial. Each token spanned approximately 700 ms, and tokens were presented at 1.5-s intervals in citation form.

### Results

A preliminary analysis was conducted to ensure that participants demonstrated recovery to the posttest stimuli and were not fatigued by the end of the task. As in previous studies employing the switch paradigm (Byers-Heinlein et al., 2013; Fennell et al., 2007), a 2 (recovery: last habituation block vs. posttest)  $\times$  2 (language group: monolingual English, bilingual English–Mandarin) mixed analysis of variance was calculated to test recovery from the last habituation block to the posttest. The purpose of this analysis is to ensure that null effects (no difference between same and switch trials) are likely not the product of fatigue or inattention during the test phase. Results demonstrated a main effect of recovery,  $F(1, 45) = 109.26, p < .0001, \eta_p^2 = .71$ . There was no main effect of group nor was there an interaction of group and recovery ( $p > .6$ ). A difference between the present study and past studies (e.g., Fennell et al., 2007; Mattock et al., 2010) was that the more rarely used infant-controlled version of the switch task was used. As such, for each experiment, habituation data were analyzed to ensure no differences in exposure to

words prior to test. Monolingual and bilingual learners were compared on total habituation time accrued. Monolingual infants accrued an average of 119 s of habituation and bilingual infants accrued an average of 113 s of habituation. Habituation times did not differ significantly across groups ( $p > .7$ ).

To determine whether monolingual and bilingual infants were sensitive to the vowel change realized in the switch trial, a 2 (test trial: same vs. switch)  $\times$  2 (language group: bilingual vs. monolingual) mixed analysis of variance was conducted. There was no main effect of trial type,  $F(1, 46) = 1.39, p = .25$ , and no main effect of language group,  $F(1, 46) = 1.08, p = .31$ . However, there was a significant interaction of trial type and language group,  $F(1, 46) = 6.30, p = .01, \eta_p^2 = .12$ . Follow-up comparisons were conducted to determine whether bilinguals and monolinguals showed the expected elevation in fixation to the switch trial as predicted when infants detect a mispronunciation. In a paired samples  $t$  test comparing fixation times to same and switch trials, monolingual infants did not show a significant difference in fixation to the visual stimulus,  $t(23) = .78, p = .44$ . By contrast, bilingual infants did show an increase in fixation during switch trials relative to same trials,  $t(17) = -3.52, p = .002$ , Cohen’s  $d = .7$ . Fixation times are graphed by group and trial type in Figure 2. Results demonstrate differential sensitivities to a vowel contrast in monolingual and bilingual infants. Although monolingual infants did not appear to detect a vowel mispronunciation during the switch trial, bilingual infants were sensitive to this change.

These findings suggest that infants were differentially sensitive to a vowel mispronunciation based on whether they were learning one language or two, even though the vowel change was contrastive in the native languages of English and Mandarin. Although this provides evidence of bilingual precocity in learning similar sounding words, it is also possible that the particular languages learned modulated vowel sensitivity. More specifically, it is

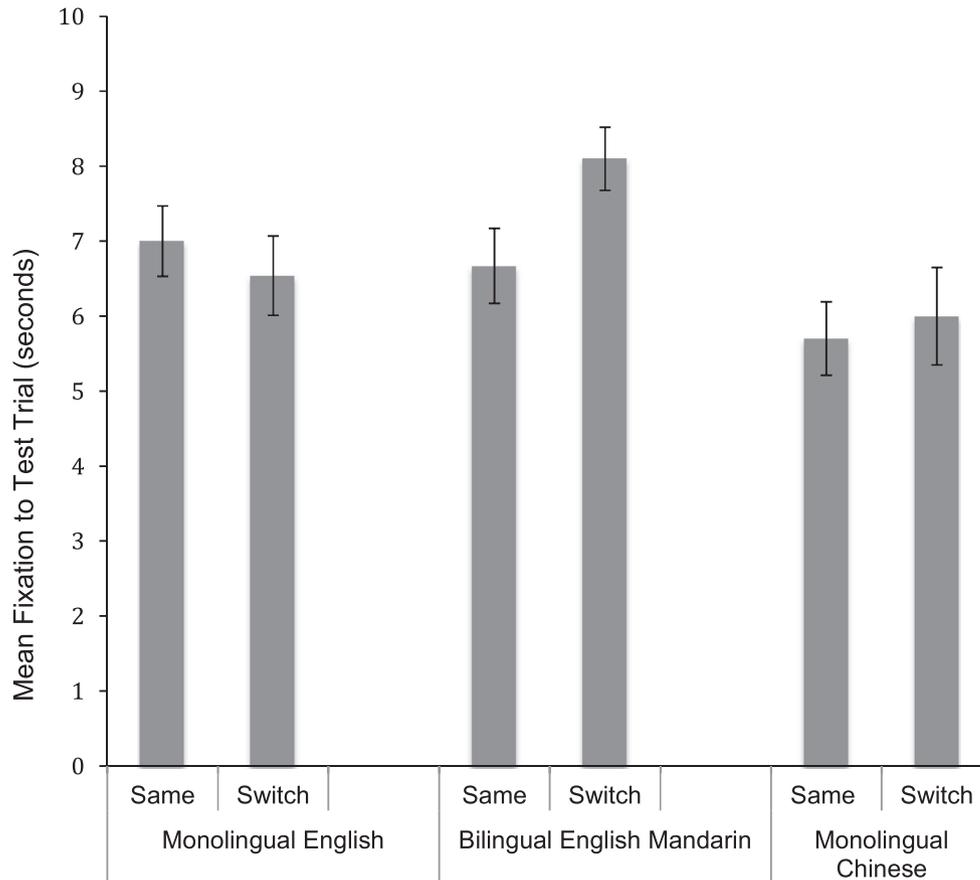


Figure 2. Fixation times to same and switch trials in monolingual and bilingual infants (Experiments 1 and 2).

possible that learning Mandarin Chinese enhances sensitivity to vowels as a source of lexical contrast. Support for this comes from evidence that suggests lexical access in learners of Mandarin Chinese is more heavily constrained by vowel identity than by consonant identity (Chen et al., 2015; Wiener & Turnbull, 2016; see also Højen & Nazzi, 2016). Studies with English speakers, in contrast, have demonstrated that consonants carry a greater lexical load than vowels (Cutler, Sebastián-Gallés, Soler-Vilageliu, & Van Ooijen, 2000; Nespors et al., 2003). It is therefore possible that the heavier influence of vowel contrasts in tone languages predisposes infants learning a tone language, albeit bilingually, to increased vowel sensitivity. To determine whether this is the case, we tested a sample of monolingual Mandarin-learning infants on the novel word-learning task employed in Experiment 1.

### Experiment 2

Experiment 2 was designed to investigate whether evidence for bilingual precocity from Experiment 1

could be attributed to increased vowel sensitivity to tone language learners as proposed in adult lexical access studies. Monolingual Mandarin-learning infants were presented with the word-learning task employed in Experiment 1 to determine whether they were able to discretely map similar sounding words onto different meanings.

### Method

#### Participants

Twenty-four infants (12 female) participated in this study, all of whom were monolingual learners of Mandarin Chinese. Infants ranged in age from 17 months 3 days to 18 months 28 days. All infants were typically developing, full-term infants with no known developmental disorders or delays. Data from four additional infants were discarded for failure to complete the testing session due to crying and inattention. Again, participants were selected based on their responses to a Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 1997). Infants were classified as

monolingual if they were exposed to Mandarin at least 90% of the time. Infants were living in a bilingual society.

### *Stimuli*

Visual stimuli were identical to those used in Experiment 1. Auditory stimuli were phonologically identical to those used in Experiment 1 with the exception that they were produced by a monolingual female speaker of Mandarin Chinese. Acoustic analyses were conducted on the stimuli as stated earlier. The auditory tokens used in this task were tokens of “mIn” and “mən,” produced by a female Mandarin monolingual speaker. Acoustic analyses of the first two formants were conducted, to provide a comparison to the stimuli used in Experiment 1. The Mandarin monolingual productions of “mIn” shared properties with both the bilingual and English monolingual productions. In particular, the Mandarin monolingual productions overlapped in F1 with the bilingual productions, but had similar F2 properties to the English monolingual productions. Specifically, like the bilingual speaker, the /i/ produced by the Mandarin monolingual speaker resembled the vowel between the English words “bin” and “been” as well, whereas the monolingual English speaker produced a word closer to “bin.” The F1 and F2 values for both words approximated values identified for Mandarin monolingual speakers (Zee & Lee, 2001). The vowel in the second token “mən” had a more distinctive profile to both the English monolingual and bilingual productions. This vowel was more fronted than the other two productions, resembling the vowel in “bun.” As with Experiment 1, there were differences in the realization of target words across speakers as would be expected by virtue of native accentedness associated with each speaker. All words were produced in Tone 1 (high tone), deemed most consistent with the infant-directed nature of the stimuli for other studies. Words received a tone assignment as tone is an obligatory feature of Mandarin Chinese.

### *Apparatus and Procedure*

The apparatus was identical to that of Experiment 1.

### *Results*

As stated earlier, a comparison of the last habituation block and the posttest trial was computed demonstrating a significant elevation in fixation during the posttest trial,  $t(23) = 5.47, p < .001$ . As in

Experiment 1, this provides an interpretative safeguard against a Type II error: In the event of a null result whereby fixation to same and switch trials do not differ, the presence of recovery indicates that this is unlikely to be accounted for by fatigue or disengagement from the experiment during the test trials. Habituation times averaged 107 s, which did not differ from habituation times for either group in Experiment 1 ( $p < .57$ ).

Of primary interest was whether participants would demonstrate sensitivity to the vowel contrast on account of being monolingual speakers of a tone language. In other words, the purpose of this study was to determine whether the bilingual advantage reported in Experiment 1 was actually a tone language advantage given the lexical reliance placed on tones in Mandarin Chinese. As such, fixation times to same and switch trials were compared in monolingual Mandarin learners (see Figure 2). Results demonstrated that as with English monolingual infants, there was no significant difference in fixation times to same and switch trials,  $t(23) = .5, p = .62$ . Results from Experiment 2 support conclusions from Experiment 1 that monolingual children may lag behind their bilingual peers in learning some types of similar sounding words. A bilingual advantage appears not to be attributable to learning a native language, such as Mandarin, that reinforces links between vowel quality and the native lexicon. Neither English nor Mandarin monolingual infants were sensitive to the vowel alternation in the present word-learning task.

Another possibility for why bilinguals may have demonstrated precocity, outside of a learning advantage conferred by multiple language exposure, could arise from phonetic properties of the bilingual speakers' input. It is possible that the bilingual speaker drew more pronounced distinctions between the vowels that favored detection of the vowel contrast. Although the formant properties of the bilingual speaker and Mandarin speaker were similar, the English speaker produced the vowel /I/ with higher F1 and lower F2 values (resembling the vowel in “bin” rather than the vowel in “been”) in accordance with native realizations of /I/ for native English speakers. This may have disadvantaged English monolinguals in discretely mapping the vowel contrastive forms onto different meanings on account of stimulus properties (although effects of speaker are potentially mitigated on the grounds that the Mandarin monolingual speaker produced stimuli that were comparably distant in formant properties to the bilingual speaker, and Mandarin monolingual infants were not sensitive to the vowel substitution).

Nevertheless, to determine whether the acoustic-phonetic properties of bilingual input may have favoured vowel sensitivity in bilingual infants, a sample of monolingual English learning infants was presented with bilingually produced stimuli provided to bilingual infants in Experiment 1. If the degree of acoustic-phonetic distinctiveness was higher in these productions in a manner that influenced word learning, monolingual infants should be able to profit from these properties of bilingual input. Experiment 3 was conducted to disentangle the relative contributions of the infant versus the input in understanding the basis for a possible bilingual advantage in vowel sensitivity.

### Experiment 3

In Experiment 3, a sample of monolingual English learners was presented with bilingual productions of the vowel contrasts used in Experiment 1. The goal of this study was to determine whether bilingual infants' abilities to learn similar sounding words in Experiment 1 were due in part by the phonetic particulars of bilingual input.

#### Method

##### Participants

Eighteen (nine female) participated in this study, all of whom were monolingual learners of English. Infants ranged in age from 17 months 0 days to 18 months 23 days. All infants were typically developing, full-term infants with no known developmental disorders or delays. Data from two additional infants were discarded for failure to complete the testing session due to crying and inattention. Again, participants were selected based on their responses to a Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 1997). Infants were classified as monolingual English speakers if they were exposed to English at least 90% of the time.

##### Stimuli, Apparatus, and Procedure

The stimuli, apparatus, and procedure were identical to those used for the bilingual sample in Experiment 1.

##### Results

As stated earlier, a preliminary analysis was conducted to determine whether there was a significant

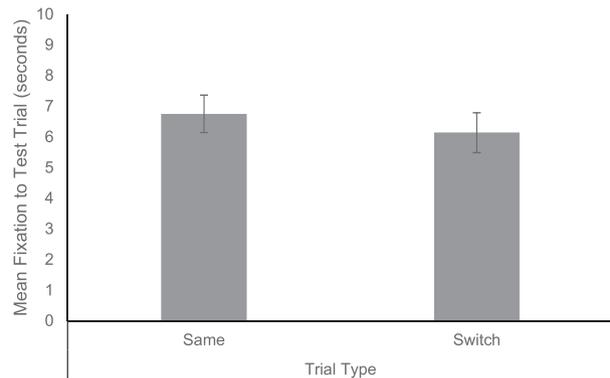


Figure 3. Fixation times to same and switch trials in monolingual and bilingual infants (Experiment 3).

difference between the last habituation block and posttest trial. Results of a paired samples *t* test comparing the last habituation block and posttest trials revealed a significant elevation in fixation times between the last habituation block and the posttest trial,  $t(17) = 2.86$ ,  $p = .01$ . Habituation times averaged 93 s. As stated earlier, habituation times were compared with bilingual infants, monolingual English infants, and monolingual Mandarin infants, reflecting no differences in total habituation time to any of these groups ( $p < .2$ ). Habituation times were lower in Experiment 3 than in Experiments 1 and 2, which may have been due to the presence of a non native speaker in Experiment 3. Primary analyses then investigated whether participants differentially fixated on same and switch trials. A paired samples *t*-test revealed no difference in fixation to same and switch trials,  $t(16) = .79$ ,  $p = .44$ . Mean fixation times to same and switch trials are plotted in Figure 3. These findings suggest that monolingual English learners did not learn similar sounding words when provided with bilingual input, suggesting that phonetic properties of bilingual input may not—in and of itself—have facilitated learning of similar sounding words in Experiment 1.

### Discussion

The purpose of the current investigation was to determine whether monolingual and bilingual infants differed in their sensitivity to vowel variation in word-learning task. In Experiment 1, monolingual English and Mandarin-English bilingual infants were taught a novel word for a novel object and presented with a correctly labeled object as well as one labeled with a vowel substitution.

Results demonstrated that bilingual infants were sensitive to the change in vowel, whereas monolingual English-learning infants were not, even though the vowel contrast was phonemic in English and Mandarin. To examine the possibility that exposure to Mandarin may strengthen vowel sensitivity in tasks that engage lexical processes due to the centrality of the vowel to the Mandarin lexicon, vowel sensitivity was examined in Mandarin monolingual infants (Experiment 2). Results demonstrated that Mandarin monolingual infants, like their English-learning monolingual counterparts, were not sensitive to the vowel contrast when learning novel words. Finally, in a third experiment, English monolingual infants were tested on the same vowel contrast as produced by the bilingual speaker used in Experiment 1 to examine whether stimulus-specific properties of the input could have facilitated performance in bilingual infants tested in Experiment 1. Results demonstrated that English-learning monolingual infants were not sensitive to the vowel contrast produced by a bilingual speaker. In the aggregate, the present set of results points us in a new direction in our understanding of the bilingual phonological lexicon, suggesting that sensitivity to some phonemic distinctions may be enhanced by bilingual exposure.

When placed in the context of prior comparisons of monolingual and bilingual infants' phonetic sensitivities, investigations into the nature of the early phonological lexicon have produced a different set of results although each of these studies have investigated single feature consonant changes. Prior studies have generally reported no differences in sensitivity to phonetic detail in word-learning tasks when both monolinguals and bilinguals are provided with input that matches their linguistic environment (Fennell & Byers-Heinlein, 2014; Mattock et al., 2010), yet both groups appear to be disadvantaged when provided with input that is mismatched with their language background (Fennell et al., 2007; Fennell & Byers-Heinlein, 2014). However, English-Mandarin bilingual infants appeared to out perform their Mandarin monolingual peers in phonological sensitivity to lexical tones (Singh et al., 2016). Singh et al. proposed a bilingual advantage in tone integration that may arise from the presence of conflict in the use of tone across the two languages of English-Mandarin bilinguals on the grounds that phonological conflict may reinforce a learner's awareness of the properties of each language. However, the present set of findings points to a bilingual advantage in vowel sensitivity relative to monolinguals under different conditions,

specifically, when the vowel contrast is phonemic in both of the languages spoken by bilingual infants (i.e., when there no phonological conflict, but there is phonological concordance). This raises the question as to why bilinguals may be advantaged in vowel sensitivity but not in consonant sensitivity when learning new words.

Three candidate reasons for a possible bilingual advantage in vowel sensitivity are offered and discussed in turn: enhanced attentional control, the presence of rich phonological input, and secondary sensitivity to vowel information as a consequence of other primary areas of bilingual enhancement (i.e., pitch, visual speech). First, prior studies have revealed bilingual advantages in learning phonologically distinct words in children (Yoshida, Tran, Benitez, & Kuwabara, 2011) and in bilingual adults (Bartolotti, Marian, Schroeder, & Shook, 2011; Kan & Sadagopan, 2014; Kaushanskaya & Marian, 2009). In an effort to identify a possible mechanism that enables better novel word learning in bilingual children, Yoshida and colleagues investigated whether a chief component of bilingual acquisition—attentional control—predicted bilingual advantages in novel word learning. Yoshida et al.'s study revealed that attentional control tasks predicted bilingual children's abilities to learn novel words rapidly and, furthermore, to exclude alternative mappings between words and meanings. The switch task employed in the present study is analogous to the preferential fixation task employed by Yoshida et al. in that it presents children with two options and involves excluding an alternative mapping (i.e., the switch trial). It is possible that a general advantage in attentional control, commonly implicated in bilingual children, strengthens performance in the switch task. However, a general word-learning advantage due to attentional control should logically be evident in consonant-contrastive words as well as vowel-contrastive words, yet such an advantage has not been found. This leads to the possibility that the bilingual advantage derives from distinct sensitivities to vowel information preferentially available to bilingual learners.

Support for a vowel-specific advantage comes from prior research that has demonstrated that bilingual infants are more sensitive to vowel contrasts in a discrimination paradigm as compared with monolingual infants (Liu & Kager, 2015). In prior studies, this advantage has sometimes been attributed to the presence of rich phonological input received by bilinguals and to consequences of rich input for forming robust phonetic

categories. Bilingual children potentially encounter substantial phonological variation in comparison to monolingual children and arguably, they may encounter richer variation within each phonological category as compared with the monolingual child. It must be noted that the hypothesis that a difference in phonetic variability exists between monolingual and bilingual environments remains speculative and awaits a more detailed corpus analysis of bilingual and monolingual input. It is therefore possible that their phonetic categories are the product of sampling a richer data set of sounds than their monolingual counterparts. In prior investigations of the effects of phonetic variability on word learning, input that is rich in variability has been shown to enhance sensitivity to segmental detail in word recognition (Schmale & Seidl, 2009; Singh, 2008) and in word learning (Rost & McMurray, 2009; see Apfelbaum & McMurray, 2011 for a discussion of variability effects on infant word learning). Specifically, the presence of high phonetic variation may highlight to infants which sources of variability are phonemic via simple statistical sampling, a learning mechanism commonly imputed to infants as a guide to native language structure (Saffran, 2003). Many statistical learning accounts of language development offer a mechanism (e.g., the Central Limit Theorem) by which phonetic categories (or in statistical terms, “distributional peaks”) that emerge from sampling a larger and more expansive distribution of values would be more pronounced than those that emerge from restricted sampling (e.g., McMurray, 2007). This provides a potential learning mechanism that links rich and variable input to phonetic category acquisition, which may have positive consequences for bilingual learners (and possibly for other groups that encounter phonetically rich input, such as biaccidental learners). A second and related point is that in the current study, the vowel distinction was phonemic in both of the bilingual participants’ languages. It is possible that phoneme contrasts that appear across both languages of a bilingual learner are more learnable than those that vary across languages, on account of transfer effects. In a similar vein, in a preferential looking paradigm implemented to measure recognition of familiar words (cognates), Ramon-Casas, Swingley, Sebastián-Gallés, and Bosch (2009) demonstrated that vowel contrasts that were present in both languages of bilingual infants were more easily detected by bilingual infants than those present in just one of their languages. It is possible that dual language “evidence” for a phonemic distinction

enhances sensitivity to the distinction relative to single language evidence.

An appeal to high-input variability to explain the bilingual advantage observed in the present study raises the question of why such advantages are not evident with consonant contrasts. Two potentially relevant factors concern the timing and nature of vowel versus consonant categories. Native vowel categories are established relatively early in the developing infant (Polka & Werker, 1994; Werker & Tees, 1984). Even subtly different native vowel categories appear to be formed and contrasted in the bilingual infant before consonant categories are established in the monolingual infant (Best, 1995; Bosch & Sebastián-Gallés, 2003; Werker & Tees, 1984). In addition, the number of to-be-established native vowel categories is smaller within the languages of our participants than consonant categories in English and Mandarin. Given these differences between vowels and consonants in early development, it is conceivable that vowel categories are relatively mature in comparison to consonant categories in infancy. It is therefore possible that rich input available to bilinguals selectively reinforces more mature phonetic categories (i.e., vowels). When considering principles of learning that link the well-formedness of a phonetic category to further learning, many statistical learning accounts predispose well-formed distributions to more efficient learning and updating based on distributional cues (Figuroa, Zeng-Treitler, Kandula, & Ngo, 2012) as well as to high sensitivity to novelty (e.g., von Luxburg & Schölkopf, 2011). In contrast, more fragile categories (due to recency of formation or weak diagnostic cues to category membership) make it harder to distinguish within- and between-category change. This could lead to selective benefits of phonologically rich input for the development of vowel categories because such categories are formulated early and may therefore be more robust. This property of vowel categories could lead to a bilingual advantage in vowel integration when learning new words. This account is currently speculative and further studies aimed at quantifying the degree of phonetic variation in bilingual environments and then seeking related evidence for consolidative effects on bilingual phonological representations for vowels and for consonants would help to evaluate this proposal.

A final possibility is that the bilingual advantage in vowel sensitivity rests on other areas of precocity previously observed in bilingual learners. Prior research suggests that bilingual infants demonstrate greater sensitivity to visually specified speech in

comparison to monolingual infants (Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012; Weikum et al., 2007). The vowel contrast in the current study is highly salient by access to visual cues; in fact, as early as 5 months of age, infants show sensitivity to the visual distinctiveness of the vowel contrast used in the present study (Kuhl & Meltzoff, 1982). Although the present study did not provide visual cues to phoneme identity, phonemic contrasts that are visually specified may be preferentially available to bilingual infants on account of prior experience with natural productions and on account of an advantage in the perception of visual cues to phonemes. One might argue that monolingual infants should demonstrate a similar advantage for visually specified contrasts. However, in light of previously reported bilingual advantages in attending to facial cues to speech, it is possible that bilingual infants are better positioned to profit from visually contrasted phonemes. In contrast, prior studies revealing no differences between monolinguals and bilinguals (e.g., Fennell & Byers-Heinlein, 2014) employed consonant contrasts that are quite difficult to distinguish using visual cues (see Dodd, 1977) and may, therefore, not capitalize on bilingual infants' perceptual proclivities toward facial cues when listening to speech.

In addition to demonstrating enhanced sensitivity to visual cues to language, bilingual infants demonstrate enhanced sensitivity to pitch movements (or vocal prosody) in speech. Bilinguals appear more sensitive to the integration of prosody and to the encoding of pitch in infancy and adulthood in comparison to monolinguals (Gervain & Werker, 2013; Krizman, Marian, Shook, Skoe, & Kraus, 2012). A relevant property of vowels is that they are heavily involved in the conveyance of pitch-driven variation (e.g., prosody) to a greater degree than consonants (Nespor et al., 2003). A vowel advantage may therefore emerge from an enhanced bilingual sensitivity to prosodic cues. Moreover, the vowel contrast employed in the present study is commonly associated with a pitch contrast, with high vowels (i.e., /I/) tending to have higher fundamental frequencies than lower vowels (i.e., /a/). In other words, vowel contrasts that are concurrently marked by pitch contrasts may selectively favor the perceptual sensitivities of bilingual infants. Prior research investigating the infant phonological lexicon reveals evidence of early biases in infancy. However, a mixed narrative is emergent with respect to the nature and determinants of early phonological biases. For example,

research using discrimination paradigms in the 1st year of life suggest that early vowel categories are established prior to consonant categories (e.g., Cutler & Mehler, 1993; Polka & Werker, 1994). Following this, in the 2nd and 3rd years of life, in word-learning and recognition paradigms, infants have demonstrated a consonant bias in some studies (Havy & Nazzi, 2009; Nazzi, 2005; Nazzi & Bertoncini, 2009; Nazzi & New, 2007) but no bias toward vowels and consonants in others (Floccia et al., 2014; Mani & Plunkett, 2008, 2010). Recent research suggests that phonological biases may be language specific (e.g., Floccia et al., 2014; Højen & Nazzi, 2016; Wiener & Turnbull, 2016) with languages that make extensive use of pitch and prosody associated with a vowel bias. By contrast, intonation languages such as French appear to be more closely associated with a consonant bias. However, other intonation languages like English are not reliably associated with a vowel or consonant bias (Floccia et al., 2014; Mani & Plunkett, 2008, 2010; but see Nazzi et al., 2009). The nature of early phonological biases appears to be heavily influenced by the structure of the native language, learners' language backgrounds, the number of languages being learned (see Havy, Bouchon, & Nazzi, 2016), and the demands invoked by testing paradigms. However, the precise effects and interactions of these factors remain undetermined as of yet, inviting scope for further research. A more elaborate view into the infant phonological lexicon could be captured by determining infants' responses to different sources of phonemic variation (vowels, consonants, and lexical tones) over time and across learners of languages that place a different linguistic premium on vowels and consonants. Within each population, a view of the maturational course of mispronunciation sensitivity would potentially shed light on the nature and language specificity of phonological biases as well as reveal some developmental determinants of early phonological biases.

In conclusion, our study demonstrates that bilingual infants appear to demonstrate precocious word learning when learning similar sounding words that vary only by vowel quality. In conjunction with previous studies in this area, it is possible that vowels and consonants differentially impact the mastery of similar sounding words. Bilinguals may have specific sensitivities and/or linguistic experiences that consolidate vowel categories earlier in development in comparison to monolingual infants. The present study suggests that monolingual and bilingual word learners may not actually develop word-learning abilities in similar ways as

suggested by prior research. When alternative units of phonology, such as vowels, are investigated, bilinguals may present with a language-learning advantage.

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