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Brief article

Development of coronal stop perception: Bilingual infants keep pace with their monolingual peers

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Abstract

Previous studies indicate that the discrimination of native phonetic contrasts in infants exposed to two languages from birth follows a different developmental time course from that observed in monolingual infants. We compared infant discrimination of dental (French) and alveolar (English) place variants of /d/ in three groups differing in language experience. At 6–8 months, infants in all three language groups succeeded; at 10–12 months, monolingual English and bilingual but not monolingual French infants distinguished this contrast. Thus, for highly frequent, similar phones, despite overlap in cross-linguistic distributions, bilingual infants performed on par with their English monolingual peers and better than their French monolingual peers.
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1. Introduction

From infant research conducted over the last two decades, we know that language experience affects infant's speech perception abilities in the first year of life (Werker,

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Gilbert, Humpfrey, & Tees, 1981; Werker & Tees, 1983; Werker & Tees, 1984; see Best & McRoberts, 2003 for a review). With age, the infant's ability to differentiate phonetic distinctions becomes more language-specific. Often this language-specificity is observed as a reduced ability to differentiate non-native phonetic distinctions that do not contrast meaning in the native language. Evidence supporting the emergence of language-specific phonetic perception is mainly from studies of English-learning infants' discrimination of non-native distinctions.

Research examining perceptual development of native phonetic distinctions in infancy is more limited. Early studies indexed *how many* infants discriminated a contrast and found that during development, the ability to differentiate native phonetic distinctions is maintained (Werker & Tees, 1984). However, recent studies that index *how well* infants discriminate a contrast show that perceptual performance on some native phonetic distinctions increases with age, pointing to a facilitative effect of language (Aslin & Pisoni, 1980; Kuhl et al., 2006; Polka, Colantonio, & Sundara, 2001; Sundara, Polka, & Genesee, 2006a; Tsao, Liu, & Kuhl, 2006). One explanation for the change from language-general to language-specific speech discrimination abilities of infants involves a domain-general, perceptual learning mechanism exploiting the infants' sensitivity to the statistical properties of the speech input (Kuhl & Meltzoff, 1996; Maye, Weiss, & Aslin, 2008; Maye, Werker, & Gerken, 2002).

To date, developmental studies of phonetic perception have focused on monolingual infants with few investigations involving infants exposed to two languages. Bosch and Sebastián-Gallés (2003a) compared monolingual Catalan, monolingual Spanish and Catalan–Spanish bilingual 4-, 8- and 12-month olds on discrimination of the /e/–/ɛ/ contrast which is phonemic in Catalan, but not in Spanish. Four-month-olds in all three groups discriminated Catalan /e/–/ɛ/. At 8-months, monolingual Catalan infants, but not monolingual Spanish infants, discriminated Catalan /e/–/ɛ/. Catalan–Spanish bilingual infants failed to distinguish Catalan /e/–/ɛ/ at 8-months, but succeeded at 12-months. Thus, discrimination of this phonetic contrast follows a different time course in monolingual and bilingual infants.

To explain these differences Bosch and Sebastián-Gallés (2003a) suggest that initially bilingual infants track statistical regularities across the two languages. These Spanish and Catalan mid-front vowels have overlapping acoustic–phonetic distributions; Spanish /e/ has first and second formant values intermediate to those of Catalan /e/ and /ɛ/. Spanish /e/ also occurs more frequently (in Spanish) compared to the Catalan vowels, making the resolution of these three vowels challenging. Bilingual infants initially form a single extended mid-front vowel category that includes all three vowels resulting in their temporary inability to discriminate Catalan /e/–/ɛ/. By 12-months, as a consequence of early word learning or increased language exposure, bilingual infants resolve the extended category into three vowel categories and thus display gains in discrimination (see also Sebastián-Gallés & Bosch, 2005).

Other studies of phonetic perception have also shown differences in the phonetic perception development of monolingual and bilingual infants. Bosch and Sebastián-Gallés replicated the pattern described above with the /s–z/ contrast which is phonemic in Catalan but not in Spanish and also with the /o–u/ distinction which is phonemic in both languages (Bosch & Sebastián-Gallés, 2003b; Bosch &

Sebastián-Gallés, 2005). When tested on the /d/–/ð/ contrast which is phonemic in English but not French, discrimination improvements emerged later in development for children acquiring French and English simultaneously compared to their English monolingual peers (Sundara et al., 2006a). A recent study comparing VOT discrimination in bilabial stops by monolingual English and bilingual French–English infants (Burns, Yoshida, Hill, & Werker, 2007) provides some evidence that monolingual and bilingual infants may not always differ in their acquisition of native contrasts (see also Burns, Werker, & McVie, 2003). The findings suggested that by 10–12 months bilinguals discriminate both an English and a French VOT difference while English monolinguals discriminate only the English VOT difference. However, there was considerable variability in each group and not all of the analyses reported uphold this pattern. Also, it is not known how perception of these French/English bilingual infants compares to their French monolingual peers.

From a distributional learning perspective (Anderson, Morgan, & White, 2003; Maye et al., 2002; Sebastián-Gallés & Bosch, 2005), discrimination of phonetic segments can be predicted by (a) overlap in distributions and (b) its frequency of occurrence. Although crowded or overlapping distributions of segments may occur in monolingual input as well, they arise more frequently in bilingual input. As in the case of Catalan /e–ɛ/ and /s–z/, overlap can occur for contrasts that are phonemic in one language but not the other. As in the case of Spanish and Catalan /o–u/, overlap can also arise for contrasts that are phonemic in both languages of bilinguals because acoustic–phonetic variability does not map onto phonetic categories precisely the same way across languages. Finally, overlap could also occur in bilingual input because of increased exposure to speech from non-native speakers (Fernald, 2006; Sundara et al., 2006a).

The present study was designed to determine whether infants are responsive to both distributional overlap and frequency of occurrence of phonetic segments in their input, consistent with a statistical learning mechanism account. If so, we expect the bilingual infant's ability to resolve overlapping acoustic–phonetic distributions to be modulated by frequency of occurrence. To test this hypothesis we compared discrimination of dental and alveolar variants of /d/ by monolingual French, monolingual English and bilingual infants. Coronal consonants, particularly /t/, /d/, are the most frequent phonemes in French and in English occurring about 9% in spoken French (Malécot, 1974) and 12–15% in spoken English (Denes, 1963; French, Carter, & Koenig, 1930; Tobias, 1959). Phonetically, in syllable initial position, French /d/ (and /t/) is transcribed as dental and English /d/ (and /t/) as alveolar. Acoustically, burst spectra and amplitude measures distinguish French[1] and English coronal stops; however, these cues show considerable overlap in productions by both monolinguals (Sundara, 2005) and bilinguals (Sundara, Polka, & Baum, 2006b). Although the dental and alveolar stop place distinction is not phonemic in either French or English, it is phonemic in several languages (Busby, 1980; Dart, 1991, 1998; Dixon, 1980). Perceptually, monolingual French adults fail to distinguish

[1] French refers to Canadian-French; English refers to Canadian-English.

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French and English /d/ while monolingual English adults succeed,[2] presumably due to the perceptual similarity of French /d/ to the English /ð/ and, perhaps, their experience with the dental–alveolar place difference for fricatives.[3] Simultaneous French–English bilingual adults also discriminate French and English /d/ even outperforming monolingual English adults in certain vowel contexts (Sundara & Polka, 2008).

We expected 6- to 8-month-olds in all three language groups to discriminate French and English /d/. Based on our adult findings, we expected monolingual English but not monolingual French 10- to 12-month-olds to discriminate this contrast. If overlapping acoustic–phonetic distributions alone pose problems for bilingual infants, then we expected to bilingual 10- to 12-month-olds to fail to discriminate this contrast. Alternatively, if distributional overlap and frequency of occurrence jointly determine discrimination difficulty, then we expect bilingual 10- to 12-month-olds to discriminate French and English /d/ because the very high frequency of occurrence of these segments in a bilingual input can offset the challenge due to overlap.

2. Methods

2.1. Subjects

The final sample included 96 infants. At each age, there were 16 infants each in the monolingual French, monolingual English and bilingual group. Subject information for each group is provided in Table 1. Twenty-three infants were excluded from analysis due to fussiness (9), caregiver's interference (1), failure to reach habituation criterion (4), computer malfunction (5) or experimenter error (4).

All infants were reported to be full-term with no health problems. Infant language exposure was assessed using a detailed parental questionnaire similar to Bosch and Sebastián-Gallés (2001). Based on parent reports of the number of hours of language use by parents, relatives and other caregivers in contact with the infant, estimates of daily exposure to French and English were derived. Infants with more than 5% overall exposure to any language other than French or English were excluded. Infants with at least 90% of their input as French-only or English-only were considered monolinguals. Infants were included in the bilingual group only if the ratio of their daily exposure to French and English ranged from 50–50% to 70–30%.[4]

[2] See Case, Tuller, and Kelso (2003) for additional evidence that monolingual English listeners are able to distinguish dental and alveolar stops.

[3] We thank a reviewer for pointing out that adult English listeners may have experience with speakers of varieties of English with dental articulations of English coronal stops (e.g. some Scottish English varieties like in Glasgow, Stuart-Smith, 1999). This experience with dental–alveolar coronal stops might also contribute to the success of English adults.

[4] Among the bilingual 6- to 8-month-olds, 4 had more exposure to French, 8 to English, and 4 had equal exposure. Among the bilingual 10- to 12-month-olds, 7 had more exposure to French, 8 to English, and one had equal exposure to both languages.

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Table 1
Subject sample: the age of infants is specified in months:days

Variables	6–8-month-olds			10–12-month-olds		
	French	English	Bilingual	French	English	Bilingual
Mean age	7:08	7:14	6:28	11:07	10:25	11:08
Age range	5:23–8:16	6:04–8:25	5:27–8:14	10:03–12:14	10:01–12:14	10:06–12:10
# girls/# boys	8/8	6/10	8/8	8/8	8/8	8/8

2.2. Stimuli

The stimuli were six French and six English /dæ/ syllables, excised from /d/-initial French and English words produced by three native monolingual male talkers of each language. These stimuli have been used previously to test adults. All tokens were digitized at 22 kHz and 16-bit quantization. They were acoustically analyzed and edited using PRAAT (Boersma & Weenink, 2005); the syllables were matched for duration, intensity, fundamental frequency, voice onset time and vowel quality (for details, see Sundara & Polka, 2008). A separate stimulus file was created for French and English stimuli. Each stimulus file was a 15.9 s random sequence of different tokens with an inter-stimulus-interval of 1000 ms.

2.3. Procedure

Infants' were tested using a partially infant-controlled visual habituation procedure (Werker et al., 1998) implemented using Habit 2000 (Cohen, Atkinson, & Chaput, 2000). The infant sat on the caregiver's lap at a distance of 150 cm facing a 21″ television screen in a curtained soundproof booth. Audio TRAK BSI-90 loudspeakers and a SONY digital video camera were located behind the curtain below the TV screen. An experimenter located outside the booth observed the infant on a monitor connected to the camera. At the beginning of each trial, a flashing red light appeared on the TV screen to attract the infant's attention. Once the infant looked at the light, a black-and-white checkerboard appeared on the screen accompanied by an auditory stimulus. The experimenter recorded the infant's visual fixation to the checkerboard during auditory presentation to index the infant's listening time. Trial durations were fixed. At the end of each trial, the red flashing light appeared again to begin a new trial. The parent and experimenter wore Peltor headphones and listened to music to prevent influencing the infant's behavior.

The experiment included four consecutive phases: pre-test, habituation, test, and post-test. Pre- and post-tests consisted of one trial in which infants listened to an animated female voice repeating the syllable 'pok' to monitor infants' attention to the task. During the habituation phase, half the infants within each age and language group heard four French tokens while the other half heard four English tokens. Infants heard tokens from only two of the three native talkers. The habituation phase continued until the looking time for the last three consecutive trials dropped below 50% of the looking time for the longest three consecutive trials. During the

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test phase, four trials were presented in a fixed ABAB order. All test stimuli were produced by new talkers. In ‘A’ trials, two tokens from the novel category (not heard during habituation) were presented; in ‘B’ trials, two tokens from the familiar (habituation) category were presented.

3. Results

All six groups of infants were comparable on pre- and post-test listening times (Table 2). To determine whether infants in the three language groups differed in their interest in the task, mean habituation times were compared using one way ANOVAs separately for each age group. For the 6- to 8-month-olds, there was a significant difference in habituation time across language groups, $F(2,45) = 5.55$, $p = .007$; French and bilingual infants were comparable, but listened significantly longer than the English infants. For the 10- to 12-month-olds, there was no significant difference in habituation time across language groups, $F(2,45) = 1.36$, *n.s.* A similar pattern of results was obtained for number of trials to habituation.[5]

Listening times for the two novel (A) and the two familiar (B) trials were averaged (Fig. 1). To demonstrate discrimination, infants had to listen significantly longer to novel trials compared to familiar trials. Repeated-measures ANOVAs were carried out with Trial-Type (familiar vs novel) as the within-subjects variable and Age (6–8 vs 10–12 months) and Habituation Stimuli (English vs French) as the between-subjects variables for monolingual French, monolingual English and bilingual infants separately. When interactions or main effects were significant, paired-comparisons were carried out separately for the two age groups.

For French infants, the interaction of Trial-Type and Age was significant, $F(1,28) = 8.9$, $p = .006$, $\eta^2 = 0.17$; the main effect of Trial-Type was also significant, $F(1,28) = 15.12$, $p = .001$, $\eta^2 = 0.28$. The 6- to 8-month-olds listened significantly longer to novel ($M = 9.66$, $SE = 0.88$) when compared to familiar trials (5.79, 0.37), $t(15) = 3.98$, $p = .001$. The 10- to 12-month-olds displayed comparable listening time to novel (7.00, 0.74) and familiar trials (6.5, 0.87), $t(15) = 0.97$, $p = .348$.

For English infants, only the main effect of Trial-Type was significant, $F(1,28) = 25.4$, $p < .001$, $\eta^2 = 0.47$. The 6- to 8-month-olds listened significantly longer to novel (9.61, 0.88) when compared to familiar trials (6.54, 0.56), $t(15) = 4.61$, $p < .001$. The 10- to 12-month-olds also listened significantly longer to novel (9.04, 0.88) when compared to familiar trials (6.52, 0.80), $t(15) = 3.02$, $p = .009$.

[5] For each age group, each variable in Table 2 were also analyzed in a Language Group by Habituation Stimuli (English or French /d/) ANOVA. For 10- to 12-month-olds, there was no main effect of habituation stimuli or interaction with Language Group for any of the variables. For 6- to 8-month-olds, there was no main effect of habituation stimuli or interaction with Language group on pre- or post-test listening time. The habituation time ANOVA showed a significant Habituation Stimuli by Language Group interaction, $F(2,42) = 4.1$, $p = .02$. ANOVA results for number of trials to habituation were identical to that for habituation time. The French 6- to 8-month-olds had longer habituation times and more trials to habituation when habituated to French stimuli than to the English stimuli.

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Table 2
Average listening times to habituation, pre-, post-test stimuli (s) and number of trials to habituation for all infant groups

Variables	6–8-month-olds			10–12 month-olds		
	French	English	Bilingual	French	English	Bilingual
Pre-test	15.1	15.2	15.5	15.5	15.3	15.4
Habituation time	116.2	83.5	117.9	105.9	111.8	85.5
Trials to habituation	10.8	8.6	11	10.4	11.2	8.2
Post-test	15.2	13.6	15.3	13.9	13.5	14.8

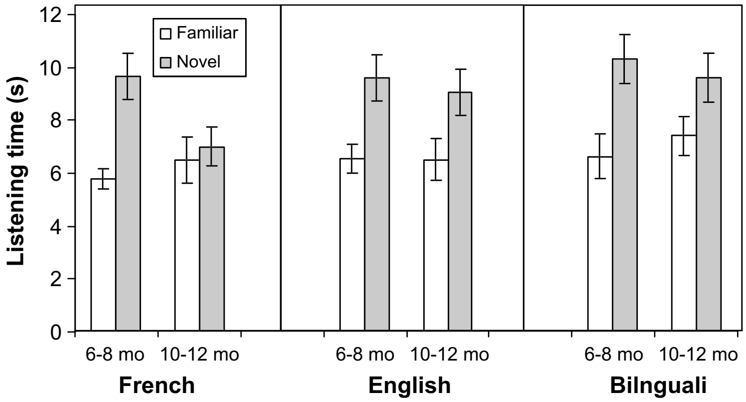

Fig. 1. Average listening time (s, $\pm SE$) to familiar and novel trials for French, English and Bilingual infants ($n = 16$ per age group).

The ANOVA for bilingual infants showed the same pattern as that for monolingual English infants. Only the main effect of Trial-Type was significant, $F(1,28) = 18.4$, $p < .001$, $\eta^2 = 0.37$. The 6- to 8-month-olds listened significantly longer to novel (10.31, 0.93) when compared to familiar trials (6.62, 0.85), $t(15) = 4.01$, $p = .001$. The 10- to 12-month-olds also listened significantly longer to novel (9.59, 0.94) when compared to familiar trials (7.4, 0.74), $t(15) = 2.22$, $p = .04$.

Performance of individual subjects was also compared. For each infant, listening times in the test phase were used to calculate a discrimination ratio (listening time to novel stimuli/sum of listening time to novel and familiar stimuli); ratios above 0.50 indicate a novelty preference. Individual discrimination ratio scores for each Age and Language group are shown in Fig. 2. Following Arterberry and Bornstein (2002), a criterion discrimination ratio significantly above chance was determined (dashed line in Fig. 2).[6] For each language group, the proportion of infants falling above this cri-

[6] A criterion discrimination ratio (DR) above chance (0.50) was calculated from the formula: Effect size = $(DR_{\text{above chance}} - DR_{\text{chance}})$/Pooled Standard deviation, using a moderate effect size of 0.5 (Cohen, 1988) and a pooled standard deviation for all six groups of infants.

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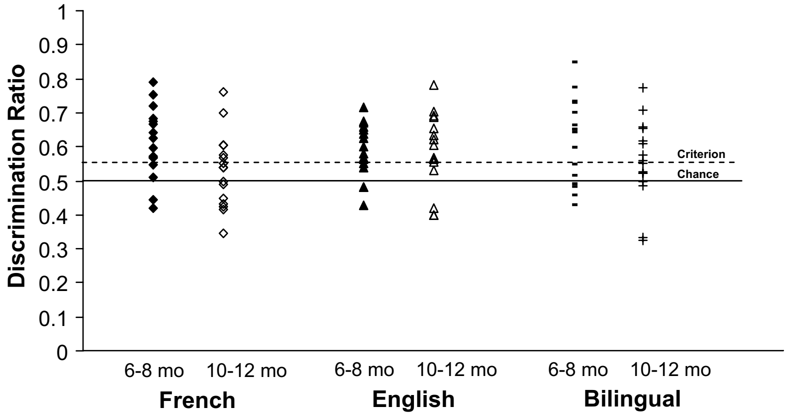

Fig. 2. Discrimination ratios for individual subjects are presented; the dashed line indicates the criterion (0.55) above which novelty preference is significantly above chance (0.50).

terion score was compared across age groups in a χ^2 test. The results paralleled the ANOVAs reported above. Proportion of infants exceeding criterion did not change with age in the English and bilingual groups; a significantly lower proportion of infants exceeded criterion in the older compared to the younger French group, $\chi^2(1) = 4.5$, $p < .05$.

4. Discussion

We compared monolingual English, monolingual French and bilingual infants in two age groups on their discrimination of French /d/ and English /d/. Variants of /d/ in French (dental) and English (alveolar) do not contrast meaning in either language. Further, the distribution of acoustic–phonetic cues for these coronals overlaps considerably when produced by monolingual or by bilingual talkers. As expected, 6- to 8-month-olds in all language groups discriminated French and English /d/. At 10- to 12-months, in keeping with predictions based on adult perception, monolingual English infants, but not monolingual French infants, succeeded in discriminating this contrast.

If overlapping distributions alone pose problems for bilingual infants, we expected bilingual 10- to 12-month-olds to have difficulty discriminating dental–alveolar variants of /d/. However, the bilingual 10- to 12-month-olds were successful at discriminating dental and alveolar variants of /d/; they performed on par with their English monolingual peers and better than their French monolingual peers. This was indicated in the comparison of group as well as individual data. Thus, bilingual and monolingual infants how similar time course of development when they encounter phonetic segments with overlapping distributions where the constituent segments have a high frequency in their input.

These findings demonstrate that development of phonetic perception in bilingual infants is not simply slower than that of monolingual infants. Rather, the time course

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of development of phonetic perception in bilingual infants is determined by the acoustic–phonetic properties of their input such that the degree of challenge posed by overlapping distributions depends on the frequency of occurrence of the constituent segments. Even a rough estimate of the frequency of occurrence, as has been used in this study, improves prediction of the trajectory of bilingual phonetic development.

The finding that statistical input properties, defined in terms of distributional overlap and frequency of occurrence of segments, can explain different patterns of phonetic perception strengthens the support for the role of statistical learning mechanisms in general and also leads to some intriguing empirical predictions for bilingual perceptual development in particular. For example, if bilingual experience increases the frequency of occurrence for a contrast occurring in both input languages, bilingual infants may show accelerated tuning-in into native language perceptual categories compared to one or both of their monolingual peers. Further, that bilingual infants' developmental trajectory differs from monolingual infants for the perception of some but not all phonetic contrasts, highlights the need to investigate the relationship between speech perception and later language development separately for bilingual infants. Finally, although similar in the timing of development, potential qualitative differences in the phonetic representations of bilingual and monolingual infants remain to be determined.

To summarize, in prior work bilingual and monolingual infants differ in the time course of perceptual development for native phonetic segments. In this study, we show that reported differences between monolingual and bilingual infants cannot be ascribed unequivocally to the crowded and overlapping phonetic distributions in the bilingual input. Even when faced with contrasting phones having overlapping cue distributions, bilingual infants keep pace with their monolingual peers; they develop detailed phonetic representations that accurately reflect their bilingual phonetic world. Comparisons of monolingual and bilingual phonetic development promise to provide valuable insights into the perceptual adaptations that unfold in the early language acquisition.

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