Language-experience facilitates discrimination of /d-ð/ in monolingual and bilingual acquisition of English

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Abstract

To trace how age and language experience shape the discrimination of native and non-native phonetic contrasts, we compared 4-year-olds learning either English or French or both and simultaneous bilingual adults on their ability to discriminate the English /d-ð/ contrast. Findings show that the ability to discriminate the native English contrast improves with age. However, in the absence of experience with this contrast, discrimination of French children and adults remained unchanged during development. Furthermore, although simultaneous bilingual and monolingual English adults were comparable, children exposed to both English and French were poorer at discriminating this contrast when compared to monolingual English-learning 4-year-olds. Thus, language experience facilitates perception of the English /d-ð/ contrast and this facilitation occurs later in development when English and French are acquired simultaneously. The difference between bilingual and monolingual acquisition have implications for language organization in children with simultaneous exposure.

Introduction

Cross-language research with infants has shown that 6-month-olds learning English are able to discriminate phonetic contrasts that are difficult for 10- to 12-month-olds and English adults (Werker & Tees, 1984; for a review see Best, 1994; Werker & Tees, 1992). Typically during development, as a result of increasing language experience, infants' discrimination performance is maintained for contrasts that are linguistically relevant in the native language and reduced for contrasts that are not. Thus, developmental changes occurring in the first year result in increased language specificity of discrimination abilities. By adulthood, a "Native Language Filter" is in place. Consequently, adults often find it difficult to distinguish non-native contrasts (Goto, 1971; Iverson & Kuhl, 1996; Miyawaki, Strange, Verbrugge, Liberman, Jenkins & Fujimura, 1975; Strange & Dittman, 1984; Werker, Gilbert, Humphreys & Tees, 1981). This maintenance (or decline) view is often interpreted to mean that development of phonetic perception involves selection, as posited by Chomsky (1959). However, absence of language experience does not always result in a decline in discrimination ability (Best & McRoberts, 2003; Best, McRoberts & Sithole, 1988; Polka & Bohn, 1996; Polka, Colantonio, & Sundara, 2001). Furthermore, the perceptual abilities of 12-month olds are far from adult-like. Thus, development is likely to involve more than a simple process of paring down or pruning discrimination abilities until only those that are meaningful in the target language remain.

Findings from a recent developmental cross-language study suggest that language experience can also facilitate or improve perception of a native contrast, whereas, in the absence of exposure to the contrast, the performance of non-native listeners remains unchanged during development (Polka et al, 2001; see Aslin & Pisoni, 1980 for introducing facilitation as one possible mechanism by which language experience may affect speech discrimination). Using the conditioned headturn procedure, Polka et al. (2001) tested 6- to 8-, and 10- to 12-month-olds exposed to either English or French and native monolingual adult speakers of each language on their ability to discriminate the English /d-ð/ contrast. This contrast is neither phonemic nor allophonic in French. French has a voiced dental stop /d/ but no voiced or voiceless inter-dental fricative. French Canadians who have learned English as a second language typically substitute /d/ for English /ð/ and /t/ for English /ɵ/[1]. Polka et al.'s results indicated that infants in both language groups were able to distinguish the English /d-ð/ contrast, regardless of age or language experience. Because the French-learning infants did not differ in their discrimination abilities from the English-learning infants at either 6- to 8-months or at 10- to 12-months of age, there was no evidence for a decline in discrimination performance in the absence of language experience at the end of the first year of life. Furthermore, the French-speaking adults were no different from the 6- to 8- or 10- to 12-month-olds, indicating that a lack of language experience results in maintenance of their initial discrimination abilities. Although the performance of the French-speaking adults was significantly above chance, it was not as good as would be expected for native contrasts. English-speaking adults, in contrast, were at ceiling in discriminating this contrast. Given that English-speaking adults were significantly better than English-learning 6- to 8- and 10- to 12-month-olds, Polka et al.'s results suggest that facilitation of initial discrimination abilities, that is, perceptual-learning occurs at some point between one year and adulthood.

[1] This pattern of substitution is different from that observed in European French where typically English /Δ/ is substituted by /s/.

Evidence for a facilitative role of language experience as reported by Polka and colleagues (see also Tsao, Liu, Kuhl & Tseng, 2000, 2002) suggests an important role for language experience after the first year of life. However, direct evidence to indicate that phonetic discrimination abilities improve after the first year of life is scarce. Research with pre-school children, often restricted to testing identification of native contrasts using natural productions, shows that they are able to differentiate many native language phonemic contrasts, although some contrasts are differentiated more easily than others (Eilers & Oller, 1976; Locke, 1971; see Barton, 1980 and Strange, 1986 for reviews). Several studies utilizing the categorical perception paradigm with children between 3 and 6 years of age reveal patterns that are adult-like in most respects when stimuli contain multiple acoustic cues to a native contrast[2] (Mann, Sharlin, & Dorman, 1985; Morrongiello, Robson, Best & Clifton, 1984; Strange & Broen, 1980; Wolf, 1973; Zlatin & Koenigsknecht, 1975). These studies of native phoneme perception provide some insights into the development of phonetic perception in the native language beyond the first year of life. However, to date, age effects on perception of both native and non-native contrasts in children older than 12 months of age have been examined only in a few cross-language studies. Such studies are necessary if we are to understand how language experience shapes development of phonetic contrasts beyond the first year of life.

Even with respect to perception of native language contrasts, our understanding of age effects is further limited by the differences in the tasks that have been used to test infants and young children. With infants, studies have focused on investigating discrimination abilities using techniques like the conditioned headturn or the visual habituation procedure in which infants' differential response to tokens from the same and different categories is taken as

[2] However, when only a single cue is varied to create a synthetic continuum, improvement with age towards a more

evidence for discrimination. In contrast, studies investigating children's perceptual abilities test spoken-word recognition or identification, typically using tasks that require differential association of the spoken-words and some referents - objects, pictures or labels (but see Gerken, Murphy & Aslin, 1995; Graham & House, 1971). Given that children's performance in such tasks is strongly influenced by whether or not the two words that constitute the test pair are part of their expressive vocabulary, poor performance in such tasks may be due either to their failure to attach the proper label to a referent or to their poor discrimination of the underlying contrast (Barton, 1976). Furthermore, age differences in comparisons of infants and children may also be attributed to the high memory load in the labeling tasks often used with pre-school children when compared to the discrimination tasks used with infants where memory load is minimized.

Therefore, in order to trace how language experience shapes the developmental trajectory of phonetic perception abilities across the lifespan, cross-language studies are needed in which similar tasks are used to test infants, children, and adults. To document changes in discrimination of the English /d-ð/ contrast during development, we tested monolingual 4-year-olds learning English or French using a modified version of the conditioned head turn response used with infants and adults in Polka et al. (2001). Previous research has shown that 4-year-olds can reliably perform a modified version of the conditioned headturn procedure (Werker & Tees, 1983). Furthermore, language effects have been previously reported when 4-year-olds have been tested in cross-language experiments using tasks similar to those used with infants and adults (Burnham, Earnshaw & Clark, 1980; Insabella & Best, 1990; Werker & Tees, 1983).

Using a modified version of the conditioned head turn procedure used with infants, Werker and Tees (1983) tested 4-, 8- and 10-year-old English-learning children on their ability

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adult-like pattern is observed with most of the significant changes occurring in the pre-school and early school age to discriminate two Hindi contrasts - the dental-retroflex (/t̪/ - /ʈ/) contrast and the dental aspirated-breathy voiced (/t^h/ - /d^h/) contrast - and a native English /ba/ - /da/ contrast as a control for task performance. Instead of turning their head to a change, children were required to press a button when they detected a change in the stimulus. As in the case of infants, the children's correct responses were reinforced by illuminated moving toys. Two main findings emerged from Werker and Tees's study. First, all three groups of English-learning children had difficulty discriminating the two Hindi contrasts, but not the English contrast[3] indicating that children between 4 and 8 years of age have difficulty with non-native but not native contrasts. Second, compared to the English-learning 6- to 8-month-old infants (Werker, Gilbert, Humphreys & Tees, 1981), the English-learning 4-year-olds were significantly poorer at discriminating both contrasts; however, the English-learning 4-year-olds were not different from English adults on their ability to discriminate either contrast. Thus, the decline in discrimination abilities observed within the first year of life in the absence of language experience continues to be evident through the pre-school and school years.

Burnham, Earnshaw and Clark (1991) and Insabella and Best (1990) also report a similar pattern of results with young children tested on the native and the non-native contrasts. In all three cross-language studies, children show reduced discrimination of non-native contrasts when compared to 6- to 8-month olds. Unlike the pattern observed in Polka et al. (2001), none of the studies report improved performance of children on native contrasts.

In the present study, the discrimination performance of 4-year-olds learning either English or French was compared. Further, we were able to compare the discrimination

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years (Krause, 1982; Williams, 1979; Wolf, 1973; Zlatin & Kenigsknecht, 1975).

performance of the 4-year-olds to the discrimination performance previously reported in Polka et al. (2001) for 10- to 12-month-olds and to adults learning English and French because of the almost identical procedure used in the two studies. Based on the results reported in all four studies - Polka et al. (2001), Werker and Tees (1981), Burnham et al. (1991) and Insabella and Best (1990) - we expect that English-learning and French-learning 4-year-olds will differ in their ability to discriminate the English /d-ð/ contrast.

However, the studies differ in their predictions of the expected developmental pattern for native and non-native contrasts. Based on the age effects reported in Polka et al. (2001), extended experience with English should facilitate the ability of English learning 4-year-olds to discriminate the native /d-ð/ contrast. Therefore, the performance of the English-learning 4-year-olds should be better than that previously reported for English-learning 10- to 12-month-olds. Alternatively, based on the results of Werker and Tees (1983), Insabella and Best (1990) and Burnham et al. (1980), absence of experience with English should result in a decline in the ability of French-learning 4-year-olds to discriminate the non-native /d-ð/ contrast. Therefore, the performance of French-learning 4-year-olds should be poorer than that previously reported for French-learning 10- to 12-month-olds.

To further investigate the role of language experience in modulating the discrimination abilities of children, we tested simultaneous bilingual 4-year-olds exposed to both English and French from birth. In recent years, there have been a few investigations of the effects of simultaneous exposure to two languages on development of phonetic perception abilities of infants (Bosch & Sebastián-Gallés, 2003a, 2003b; Burns, Werker & McVie, 2003). From

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[3] Werker and Tees also tested 2 Hindi-learning children aged 4 and 5 to ascertain that the poor discrimination

investigations of infants learning two languages, it appears that dual language exposure can alter the time course or rate at which the phonetic discrimination abilities of infants exposed to two languages become language-specific. Specifically, infants receiving bilingual exposure show language-specific discrimination abilities at a later age when compared to infants receiving monolingual exposure. When infants were tested on contrasts that are phonemic in only one of the two languages of the bilingual, a difference in rate of development has been reported for vowels (Bosch & Sebastián-Gallés, 2003a) and for fricative voicing contrasts (Bosch & Sebastián-Gallés, 2003b). Developmental data on the discrimination of voice-onset-time differences signalling voicing distinctions (Burns et al., 2003) are also consistent with a difference in rate of development between bilingual and monolingual infants.

To test whether differences in rate of development are evident for discrimination of the English /d-ð/ contrast at 4-years, we compared the discrimination performance of bilingual children exposed to both English and French with that of monolingual 4-year-olds exposed to either English or French. The bilingual group was matched to the monolingual group on two variables that are likely to influence their discrimination abilities – receptive language proficiency and production ability. The monolingual and bilingual groups were matched on their receptive vocabulary scores in English and in French as measured by the Peabody Picture Vocabulary Test (Dunn & Dunn, 1981; Échelle de vocabulaire en images Peabody - Dunn, Thériault-Whalen, & Dunn, 1993). Further, the monolingual English-learning 4-year-olds and the bilingual 4-year-olds were matched on their ability to imitate /ð/- initial and medial words as some researchers (Vihman, Macken, & Miller, 1985; Vihman & Nakai, 2001) have suggested

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performance of English-learning 4-year-olds could not be attributed to the inability of 4-year-olds to perform the task. Both Hindi-learning children were able to discriminate the two Hindi contrasts with ease.

that the emerging speech production skills of language learners may serve to modulate changes in cross-language speech perception abilities. Finally, to confirm that differences (if any) between the bilingual and monolingual children are due to differences in rate of development, adults exposed to both English and French from birth were also tested. To provide strong evidence for difference in rate of development two findings were expected. First, a reduced discrimination performance was expected from bilingual 4-year-olds when compared to monolingual English-learning 4-year-olds. Second, simultaneous bilingual adults were expected to be better than bilingual 4-year-olds, but not different from English-speaking adults in their ability to discriminate the English /d-ð/ contrast.

Method

Stimuli

A modified version of the stimuli used by Polka et al. (2001) were used in this study. In Polka et al. (2001), the stimuli consisted of two sets of naturally produced English minimal word pairs, /bot-vot/ (“boat”-“vote”) and /doz-ðoz/ (“doze”-“those”) produced by a monolingual English speaker. The /b-v/ pair was used as a control for task performance because the phonemes /b/ and /v/ occur in both French and English and contrast the same manner classes (voiced stop versus voiced non-sibilant fricative) and similar place differences as /d-ð/. Additionally, the vowel /o/ was selected as it has similar acoustic characteristics across the two languages. Thus, it was possible to assess whether each infant could perform the task with a native contrast before introducing the /d-ð/ contrast that is not native for the French infants. Details of the acoustic characteristics of the stimuli are presented in Polka et al., 2001.

In the present study, because we were testing 4-year-olds (not infants) an additional variable, the lexical status of the test words was also controlled. Most English-learning 4-year-olds are familiar with the word “boat” but not the word “vote” whereas French-learning 4-year-olds are unfamiliar with both “boat” and “vote”. To equate for differences in familiarity and lexical status across the two language groups, we edited the English /bot-vot/ by deleting the final /t/ from both words to obtain the /bo-vo/ (“beau”-“veau”) contrast. Because lengthening the vowel is likely to increase backward masking effects, the vowels in the /bo-vo/ contrast were not lengthened. Even with the shorter syllable durations, monolingual French speakers found the syllables with the final stop truncated to be quite natural sounding and readily identifiable as the target words “beau” and “veau”. Most French-learning 4-year-olds are familiar with the word “beau” (beautiful) but not the word “veau” (veal). The contrast /bo-vo/ (as opposed to /bot-vot/ with English-learning children) was used as a control for task performance with French-learning children.

For the /doz-ðoz/ contrast, English-learning children are familiar with both /doz/ and /ðoz/ whereas French-learning children are unfamiliar with both /doz/ and /ðoz/. To equate for differences in familiarity and lexical status across the two language groups, we edited the final /z/ from both words to obtain the /do-ðo/ (“doe”-“though”) contrast; both words are not likely to be familiar to either English-learning or French-learning children. Removal of the final /z/ also resulted in an open syllable, an acceptable syllable shape in both English and French. The /do-ðo/ contrast was used as test contrast for the 4-year-olds in all language groups. In the final set, the /bot/ and /vot/ tokens had a mean duration of 325ms (range=285.5 to 327.4ms), the /bo/ and /vo/ tokens had a mean duration of 160.1 ms (range = 141 to 175ms) and the /do/ and /ðo/ tokens had a mean duration of 309.2 ms (range = 288 to 333ms).

Procedure

Parent reports were used to ascertain the children's exposure to and spontaneous use of the target language(s). Their receptive language proficiency was assessed using the PPVT. The PPVT was administered in French to French-learning children and in English to English-learning children. All 4-year-olds were first administered the PPVT by a fluently bilingual experimenter with no detectable accent in either language. This helped the testers to build a rapport with each child. Children were then tested on the speech discrimination task, /b-v/ followed by /d- ð/ (described below). Finally, they completed a brief imitation task. Total testing took about 30 to 45 minutes during which the children were given ample breaks and small stickers and gifts as reinforcements. Adults completed the language questionnaire and were then tested on the speech discrimination task.

Speech discrimination testing was completed in the same test environment using the same instrumentation as in Polka et al (2001). The children were tested using the headturn procedure for infants described in Polka et al. (2001) with only minor modifications to facilitate testing with 4-year-olds. In Polka et al. (2001) infants were tested in 2 sessions - /b-v/ was tested on day 1, and /d-ð/ on day 2. The 4-year-olds were tested on both contrasts the same day because few 4-year-olds in pilot testing were attentive for 2 sessions.

During testing of the 4-year-olds, parents were not present in the sound booth; children were seated on a small chair across a table from an experimenter (E1). The loudspeaker and an array of four visual reinforcers, located behind a smoked plexiglass panel, were located to the left of the child. E1 listened to vocal music over headphones to prevent her from influencing the infant's behavior. A second experimenter (E2) located outside the test room observed the child through a one-way window and operated the computer.

Once the child was seated, a syllable was played on the loudspeaker every 1500ms, and at different points in time the background syllable changed to a target syllable for a brief interval. The loudspeaker was "dressed-up" to resemble a robot (based on Morrongiello et al., 1984). Children were told that the "robot" needed help in order to learn to say /bot/ (or /bo/ or /do/). They could help the robot by pressing a button when the robot was "right". Thus, in lieu of a headturn, the 4-year-olds were conditioned to press a button. E2 recorded button presses as signalled by illumination of a light bulb connected to the button.

Results from pilot testing indicated that 4-year-olds could only be kept on task by instructing them to listen for a word. The English children were presented /vot/ as background and were asked to push the button when they heard /bot/. French children were presented /vo/ as background and asked to push the button when they heard /bo/. All bilingual children were presented /vot/ as background and asked to push the button when they heard /bot/.

Testing was done in two stages – the conditioning stage and the testing stage. During the conditioning phase, correct button presses were reinforced by turning-on the visual reinforcer (an electronic animal that moves) and with verbal praise from E1. The 4-year-olds also occasionally received rewards (stickers) from E1 during testing. Following three correct button presses, the testing stage began. During the testing stage, both change and no change (control) trials were presented in a semi-random schedule in which no more than 3 consecutive control or change trials occurred. E2, blind to the nature of the trial (whether change or control), pushed a button to record the child's response. There is also a provision for re-training trials (a maximum of 6). These trials are excluded from analyses.

All children were first tested on the /b-v/ contrast till they reached a criterion of 8/10 consecutive correct responses, or for a maximum of 20 trials. Thus, unlike in Polka et al. (2001), all children did not hear 25 /b-v/ trials. If children met criterion on the /b-v/ contrast, testing was terminated for the contrast and the children were immediately tested on the /d-ð/ contrast. If the children did not meet criterion on the control /b-v/ contrast, testing was terminated. Testing on the /d-ð/ contrast was identical to that described in Polka et al. (2001). If the children failed to meet criterion on the /d-ð/ contrast, they were retested on the /b-v/ contrast till they met criterion (or for a maximum of 20 trails), as a control for task performance. All children were given small toys and their parents were presented with diplomas as tokens of appreciation for participating in the study.

The adult subjects were tested using the same basic procedure as the children and following the identical procedures used to test adults in Polka et al (2001). Each adult was seated in the same chair as the child and instructed to raise their hand on hearing a sound change. The reinforcers were activated following correct responses to change trials, just as with the children and infants. In the conditioning stage, adults were given a minimum of three and a maximum of six conditioning trials. During testing 25 test trials were presented; no retraining trials were presented. Adults were tested on the control contrast (/b-v/) and then the test contrast (/d-ð/) in a single session. They were paid for their participation.

Subjects

Thirty-six 4-year-olds (15 females, and 21 males) and twelve adults (6 females, 6 males) served as subjects. All subjects reported normal hearing and no history of speech or language disorders. The 4-year-olds included 12 French-learning children (mean age=4:10, range 4:01 to 5:06), 12 English-learning children (mean age=4:09, range 4:04 to 5 years), and 12 bilingual children (mean age=4:10, range 4 to 5:09 years) learning both French and English.

To get 36 children to complete the protocol, an additional 27 children (4 English; 8 French and 16 bilingual) were tested. Eleven children failed to cooperate in the task for several reasons; they did not press the button at all or pressed it all the time (n=5); did not complete the procedure (n=3); were afraid of the reinforcers (n=1); did not separate from their mother (n=1); or talked all the time (n=1). One additional child was excluded due to experimenter error. Additional children were excluded because they did not meet criterion on the control contrast (n=12), or because they had PPVT scores (described below) that were not age appropriate (n=3), all three of these children were monolinguals (2 English and 1 French).

To be included in the monolingual group, the children had to meet the following criteria. First, they and their parents were native speakers of the target language; second, their PPVT scores were age appropriate to rule out language delay; the average PPVT raw score for the English 4-year-olds was 115.1 (SD = 19.3; range = 91 to 156) and average for the French 4-year-olds was 118.9 (SD = 20; range = 92 to 152). Third, even if the children had a minimal exposure to another language, they did not use more than one language in their spontaneous speech.

To be included in the bilingual group, the following criteria had to be met. First, French and English were spoken in the home on a roughly equivalent basis, or the child attended a bilingual daycare or preschool program. Second, the child regularly used both languages in their spontaneous speech. Third, PPVT scores, in both French and English, were comparable to those of the monolingual children. It is important to note that age equivalent scores provided by the PPVT are based on monolingual norms and, thus, may not be valid for assessing bilingual proficiency. In our study, we used the PPVT simply as a global measure of receptive skills in order to obtain an objective and independent measure of the proficiency of the 4-year-olds. In view of this, we do not compare age-equivalents, only raw scores, and then only as a metric of comparison between the receptive abilities of the bilingual and respective monolingual groups. These comparisons should be interpreted with caution. The average PPVT raw score for the bilinguals in English was 101.3 (SD = 12.5; range = 84 to 126) and in French was 110.2 (SD = 21.3, range = 81 to 142). Using a *t*-test for comparison, there was no significant difference between the scores obtained on the French PPVT for the bilingual and the monolingual French children, $t(22) = -1.04$, $p = 0.31$; and there was no significant difference between scores obtained on the English PPVT for the bilingual group and the monolingual English children, $t(22) = -2.02$, $p = 0.06$. Details of the parent reports for the bilingual children are summarized in Table 1.

Table 1.

	Native Language		Language Input			
Child	Mother	Father	Mother	Father	Preschool	Child's Output
13F	E (f)	F (e)	50E-50F	70E-30F	100F	70E-30F
15M	E (f)	F (e)	95E-5F	95E-5F	100F	70E-30F
17M	E (f)	F (e)	90E-10F	100F	50E-50F	90E-10F
23M	E (f)	E (f)	95E-5F	100E	100F	70E-30F
29M	E/F	E	100F	100E	100F	50E-50F
35F	E/F	E (f)	10E-90F	90E-10F	50E-50F	50E-50F
39M	E (f)	E/F	90E-10F	20E-80F	100F	60E-40F
51F	E/F	E	50E-50F	100E	50E-50F	50E-50F
52F	F	E (f)	100F	100F	100E	60E-40F
57M	E/F	E/F	30E-70F	30E-70F	100F	30E-70F
60M	E	F (e)	100E	10E-90F	100F	60E-40F
62F	E/F	F	100E	100F	100F	70E-30F

Legend: A summary of parent reports of language exposure and language output of the bilingual 4-year-olds is presented in Table 1. Each subject is identified by a number followed by M/F to indicate gender. The next column lists the native language spoken by the child's parents. An upper case 'E' or 'F' represents early exposure (before 6 years of age) and native-like proficiency whereas a lower case 'e' or 'f' represents some knowledge of English or French respectively. Finally, the language input to the child and his output in the two languages are presented as percentages, with percent values given first for English, and then for French.

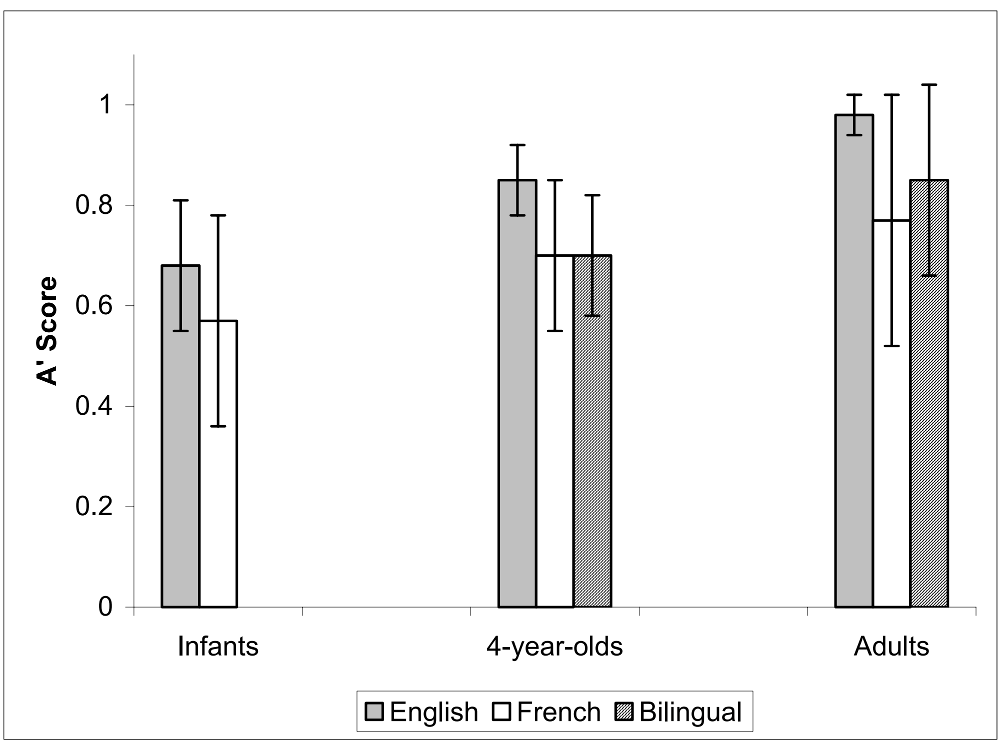
Finally, all 4-year-olds were asked to imitate the tester's production of 5 words with /ð/ in initial position (those, that, these, there and theirs) and 4 words with /ð/ in medial position (mother, father, brother and feather). Their productions were recorded using a Sony tape-recorder. Subsequently, two listeners perceptually classified the productions as correct or incorrect. On average, the monolingual English 4-year-olds produced 4.54 correct responses in initial position and 3.64 correct responses in medial position. The monolingual French 4-year-olds produced 1.91 correct responses in initial position and 0.91 correct responses in medial position. The bilingual 4-year-olds produced an average of 4.45 correct productions in initial position and 3.84 correct productions in medial position. Thus, the bilinguals and monolingual English 4-year-olds were comparable in their imitation of English /ð/ in initial and medial position; and both groups were better than the French 4-year-olds.

The adults included 12 simultaneous bilingual French-English subjects (mean age= 24:09, range 18 to 41 years). All adults filled out a language questionnaire that included their place of birth, native language of their parents, where and how they had learned any/all of the languages they spoke, and self-ratings of their proficiency in speaking and understanding and their fluency and accent in each of their languages. To be included, the simultaneous bilingual adults had to have been exposed to both languages since birth - at home from parents who were either fluently bilingual or each parent was a native speaker of either French or English. They also used both languages regularly and rated their abilities at 6 - 7 in both French and English on a scale of 1 to 7, where 1 represents no ability and 7 represents native-like ability.

Results

To analyze the effects of age and language experience, an A-Prime score [4] was computed for each individual based on the discrimination of the /d – ð/ contrast. A-prime is a non-parametric index of sensitivity (similar to d-prime) ranging from 0 to 1 (with 1 being a perfect score and 0.5 representing chance) that allows a correction for response bias (Grier, 1971). Mean A-prime scores for discrimination of /d – ð/ by the 4-year-olds and the simultaneous bilingual adults are presented in Figure 1 (see also Table 2) along with previous data from the monolingual infants and adults reported in Polka et al. (2001).

Figure 1. A-prime scores of monolingual English-learning, French-learning and bilingual English and French-learning 4 year-olds and adults are presented in Figure 1. Error bars represent SD. For comparison, the A-prime scores of the monolingual 10- to 12-month-olds and adults from Polka et al. (2001) are also presented.



[4] The formula used was A'= 0.5 + [(H – FA) (1+H-FA) / (4H(1-FA))], where H= proportion of hits and FA= Proportion of false alarms.

Table 2

Group	Infants	4-year-olds	Adults
English	0.68 (0.13) [P]	0.85 (0.07)	0.98 (0.04) [P]
French	0.57 (0.21) [P]	0.70 (0.15)	0.77 (0.25) [P]
Bilingual		0.70 (0.12)	0.85 (0.19)

Legend: A-prime scores (SD) of monolingual English-learning, French-learning 4-year olds and bilingual English and French-learning 4 year-olds and adults are presented here. For comparison, the A-prime scores of the 10- to 12-month-olds learning English, and French and adults from Polka et al. (2001) are also presented. These are identified by the superscript '[P]'.

Language-experience effects

4-year-olds

To test whether a difference in language-experience resulted in differences in the abilities of 4-year-olds to discriminate the English /d – ð/ contrast, A-prime scores of the 4-year-olds were compared in a one-way ANOVA with language-experience as the between-subjects variable (monolingual English, monolingual French, bilingual). As expected, there was a significant effect of language-experience, $F(2, 33) = 6.57$, $p=0.004$. Based on post-hoc analyses (Tukey), the monolingual English-learning 4-year-olds were significantly better than the monolingual French-learning 4-year-olds ($p=0.01$), confirming that language effects are observed in 4-year-olds listening to native and non-native contrasts. The monolingual English-learning 4-year-olds were also significantly better than the bilingual 4-year-olds ($p=0.009$), but there was no difference between the performance of the bilingual and monolingual French-learning 4-year-olds.

Adults

Further, the simultaneous bilingual adults were compared to the previous data from the monolingual English- and French-speaking adults in Polka et al. (2001), to determine whether the effects of bilingual exposure continue into adulthood. Recall that if the difference between bilingual and monolingual children reported above reflects a difference in the rate of development, no difference is expected in the performance of the bilingual adults tested in the present study and the monolingual English adults tested previously. In a one-way ANOVA, with language-experience as the between-subjects variable (monolingual English, monolingual French, bilingual), there was a main effect of language experience, $F(2, 38) = 5.18$, $p=0.01$. However, based on Tukey's post-hoc analyses, only the difference between the monolingual English- and the monolingual French-speaking adults was significant ($p=0.008$). There was no significant difference between the simultaneous bilinguals and either group of monolingual adults confirming that the differences between monolingual and bilingual children are developmentally circumscribed[5].

Age effects

To determine whether the language-experience effects observed for the 4-year-olds are due to the decline in performance for non-native contrasts or facilitation in performance for native contrasts, age effects within each of the three groups were analyzed. A one-way ANOVA with age as a between-groups variable (infants, 4-year-olds, and adults) was carried out for the monolingual English group for whom the /d – ð/ contrast is native. There was a significant difference in the A-prime scores for the three age groups, $F(2, 33) = 40.8$, $p<0.01$. Subsequent Tukey's post-hoc analyses indicated that the English-learning 4 year-olds were significantly better at discriminating the /d – ð/ contrast than the 10 to 12-month-olds (*p*=0.04); in turn, the monolingual English adults were significantly better than the 4 year-olds (*p*=0.03). A similar one-way ANOVA with age as a between-groups variable (infants, 4-year-olds, and adult) carried out on the A-prime score for the French group for whom the /d – ð/ contrast is non-native, was not significant, $F(2, 33) = 2.5$, $p=0.09$, indicating that the performance on the non-native contrast did not change with age. Finally, the discrimination performance of the bilingual 4-year-olds and adults was compared using a t-test. The bilingual adults were significantly better than the bilingual 4-year-olds, $t(22)=0.46$, $p=0.03$.

Discussion

The present study was designed to better understand developmental patterns in phonetic discrimination from infancy to adulthood and how they are shaped by language experience. To this end we compared three groups of 4-year-old children – monolingual English, monolingual French, and bilingual (French/English) – on their ability to discriminate the English /d – ð/ contrast. Because testing was conducted using a modified version of the conditioned headturn procedure used with infants and adults, we were also able to compare our data from 4-year-olds with previous data reported in Polka et al. (2001) from monolingual 10- to 12-month-old infants and adults to determine the developmental trajectory of phonetic discrimination abilities for native and non-native listeners across this wide age span.

Overall, there was a significant difference in discrimination performance by the English-learning and the French-learning children, confirming that language effects are evident by 4-years of age. Furthermore, the language effects were due to improved performance of the English-learning 4-year-olds on a native contrast as evidenced by their performance in

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[5] The maternal language of the bilingual adults did not predict discrimination performance. The 5 subjects with

comparison to English-learning infants. Thus, our results indicate that the language effects observed for 4-year-olds are a consequence of facilitation in discrimination of the native /d – ð/ contrast for children exposed to English. For the French-learning 4-year-olds, in the absence of language experience with this contrast, the discrimination abilities were maintained at the same level as those observed for French-learning infants and monolingual French adults reported by Polka et al. (2001). The bilingual 4-year-olds, whose performance in the present study differed from the monolingual English children but not the monolingual French children, did not show evidence of facilitation. The bilingual adults, however, were not significantly different from the monolingual English adults at discriminating the English /d – ð/ contrast and were better than the bilingual 4-year-olds, confirming that children exposed to one or two languages differ in the age at which the facilitative effects of language experience are observed. More specifically, based on the performance of bilingual adults, facilitative effects can be expected to emerge in bilingual children some time after 4 years and before adulthood.

The facilitation pattern observed when we compared the discrimination performance of the monolingual English-learning infants, the 4-year-olds, and the adults is consistent with predictions based on Polka et al.'s (2001) results. Furthermore, the increase in discrimination performance observed for the English-learning 4-year-olds cannot be attributed to an increase in age and concomitant cognitive maturity alone. Recall that there was no change in the discrimination performance of French-learning 4-year-olds. Our results suggest that the facilitation pattern is indeed a consequence of language experience.

There are three possible reasons why the pattern reported here is different from the maintenance versus decline pattern reported by Werker and Tees (1983), Insabella and Best

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English as their maternal language had a mean A' of 0.83 and the 7 subjects with French as their maternal language

(1990) and Burnham et al. (1991). It is possible that infants and children find it difficult to perceive the English /d – ð/ contrast due to the acoustic or articulatory characteristics of these segments. As argued in Polka et al. (2001), English /d/ and /ð/ are short, low energy segments and, thus, the difference between the two phonemes may not be salient, at least early in development (Eilers, Wilson & Moore, 1977; Fletcher, 1953; Ling & Ling, 1978). Several other researchers have suggested that the infant's sensitivity to the articulatory gesture that is perceived increases with age (Best & McRoberts, 2003; Meltzoff & Moore, 1997; Studdert-Kennedy & Goldstein, in press). Specifically, Best and McRoberts (2003) argue that infants are able to detect which articulator was used to produce a speech sound before they are able to detect how the articulator was moved to produce the speech sound. Because both English /d/ and /ð/ are produced by the tongue tip and only differ in how the tongue tip is moved, infants may require extensive language experience with the contrast before they are able to discriminate the English /d – ð/ contrast at the high levels of accuracy typically observed for native contrasts.

It is also possible that the unique distribution of English /ð/ necessitates extensive language experience before discrimination of the English /d – ð/ contrast can improve. The phonotactic properties of /ð/ are unique in English such that /ð/ occurs with a very high frequency in word-initial positions in spoken English, especially in speech to young children – but only in the context of function words (Morgan, Shi & Allopenna, 1996). In English, function words are less salient forms in natural discourse; they are short and typically, contain unstressed vowels and are not produced in isolation or highlighted by intonation (Shi, Morgan & Allopenna, 1998). There is evidence that newborns can discriminate content from function words (Shi, Werker & Morgan, 1999) and that 6-month-old English-learning infants prefer to listen to

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had a mean A' of 0.86.

content than function words (Shi & Werker, 2001) perhaps based on the above-mentioned acoustic and phonological differences between function and content words. Furthermore, recent research indicates that infants attend to phonetic detail in stressed but not unstressed syllables (Mattys, Juscyzk, Luce & Morgan, 1999) and hence, detect minimal distortions of function words at a later age compared to content words (Shi, Werker & Cutler, 2003). Finally, given that function words in English are typically weak syllables, English-learning infants are likely to segment content words earlier than function words (see Curtin, Mintz & Christiansen, in press for a detailed discussion of the role of stress in early segmentation). Given the high frequency of English /ð/ in perceptually less salient word forms, some consequences can be expected for the discrimination of segments that occur exclusively in these contexts. Specifically, the unique phonotactic properties of English /ð/ may explain why extensive experience extending beyond the first year of life is essential to observe language effects in the discrimination of the English /d - ð/ contrast.

Finally, it is also reasonable to hypothesize that accurate perception of this contrast emerging due to facilitation of discrimination after the first year in life may be shaped by top-down influence. Because English /ð/ is restricted to highly predictable function words, there is less pressure on English speakers to produce it clearly. In fact, in some dialects of English, a voiced alveolar stop /d/ is regularly produced in frequent function words that have word initial /ð/, e.g. [dat] instead of “that”. This surface variation may be ignored by adult speakers of English. Given the messy surface properties of English /ð/, it may be difficult for the child learning English to derive a functional /ð - d/ contrast from a bottom-up analysis of the language input alone. Top-down influences thus may be important in perceptually differentiating English /d/ and /ð/. Although an awareness of the abstract phonological form underlying the surface variants of English /ð/ may begin to emerge in the pre-school years, it may not be consolidated until children learn to read English (see Burnham, 2003 for a discussion of the impact on reading on speech perception skills). Children exposed to both English and French who have not had as much exposure to the /d - ð/ contrast in their input may quickly catch up with monolingual English children once they begin learning to read English and discover that /d/ and /ð/ are distinct phonological units.[6]

Evidence for a pattern of development other than the classic maintenance versus decline view has several implications for our understanding of how phonetic perception abilities develop. First, phonetic discrimination abilities continue to change from language-general to language-specific even after the 1st year of life, highlighting the need for data from pre-school and school age children using comparable methodologies. Second, the presence of a phonetic contrast in the native language input is necessary but not sufficient to predict language effects in the first year of life. Recall that there was no difference in the performance of 10 to 12-month-olds learning either English or French on their ability to discriminate the English /d - ð/ contrast. Third, language experience in early development does not merely serve to maintain the discrimination abilities of native contrasts. For some contrasts, experience is essential to bring discrimination performance of infants up to the high levels typically demonstrated by native adults.

Although there was evidence for facilitation in the discrimination of the native English /d - ð/ contrast by 4-years of age, the discrimination performance of English-learning 4-year-olds was still not as good as that of monolingual English-speaking adults. Similarly, there was a

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[6] It is also possible that, in comparison to the monolingual English children, bilingual children acquiring English and French in Montreal are exposed to more second language speakers of English who substitute the /d/ for /ð/. This substitution pattern would create a very inconsistent input from which to derive a functional /d/ - /ð/ contrast.

significant difference in the performance of bilingual 4-year-olds and adults, indicating that phonetic discrimination abilities are not completely developed by 4 years of age. However, also recall that the English-learning and bilingual 4-year-olds differed in their ability to discriminate the English /d - ð/ contrast, indicating that monolingual and bilingual children differ in the age at which language-specific changes are observed in their phonetic discrimination abilities.

Differences in rate of development between monolingual and bilingual children have implications for an understanding of the organization of the phonological system in bilinguals (see also Bosch & Sebastián-Gallés, 2003a). Early investigations of simultaneous bilingual children argued for an undifferentiated or fused language system based on the observation that they produce utterances with elements from their two languages. According to the fused or Unitary Language System hypothesis (ULS; see Genesee, 1989 for an overview), bilingual children transition from an undifferentiated system comprised of elements from both their languages to two separate systems, one for each language (Volterra & Taeschner, 1978). Early reports of this interpretation of language mixing have since been criticized on empirical and methodological grounds (Genesee, 1989; Meisel, 1989).

Recent evidence supports an alternative view of bilingual language organization, the Dual Language System hypothesis (Genesee, 1989). According to this hypothesis, bilingual children have differentiated representations of their two languages early in verbal development. There is evidence for differentiated systems in bilingual children's productions at the emerging socio-pragmatic (Genesee, Nicoladis & Paradis, 1995), syntactic (Meisel, 1990; Paradis & Genesee, 1996), as well as semantic level (Quay, 1995).

We have no data that allows us to confirm such input differences but acknowledge that such an input differences may contribute to our results.

Investigations of bilingual children's production of phonology are equivocal on the issue of a unitary or dual language system. Some researchers investigating the phonology of bilingual children have reported that they do not produce language-specific differences in vowels and consonants, supporting the ULS hypothesis (Celca-Murcia, 1978; Leopold, 1970; Vogel, 1975). Others have reported that bilingual children produce language-specific differences in some, but not all segments, supporting a partially differentiated system (Johnson & Wilson, 2002; Schnitzer & Krasinski, 1994). Still others have found that bilingual children produce language-specific differences in their two languages at all ages, thereby providing support for a fully differentiated system (Ingram, 1981; Johnson & Lancaster, 1998; Khattab, 2000, 2003; Paradis, 2001; Schnitzer & Krasinski, 1996; Watson, 1990, 1996).

There have been few studies comparing discrimination of phonetic segments by monolingual and bilingual language learners. As presented in the introduction, Bosch & Sebastián-Gallés (2003a, 2003b) and Burns et al. (2003) have compared the discrimination abilities of infants exposed to one or two languages from birth. The results from both studies indicate that there may be a difference in the rate of development of monolinguals and bilinguals, with bilingual infants evidencing language-specific behavior at a later age than monolinguals. Discrimination data from the present study also argue for differences in rate of development between monolingual and bilingual children for contrasts that occur in only one of the two languages of the bilingual child. English-learning, but not bilingual 4-year-olds, were significantly better than French-learning 4-year-olds at discriminating the English /d - ð/ contrast. By adulthood, there was no significant difference between monolingual English speakers and simultaneous bilinguals on their ability to discriminate English /d - ð/ confirming that these differences are transitory and only evident during development[7].

Because there was no difference in the receptive vocabulary or imitation abilities[8] of the English-leaning and bilingual 4-year-olds, the difference in their discrimination performance cannot be attributed to the bilingual children's poorer language skills in English. Nor can differences in monolingual and bilingual performance in this study be attributed to differences in the social status of the two languages of the children. All children tested in this study were from the Montreal and Ottawa regions, where French and English enjoy near-equal and high status in all spheres.

Differences in rate of development in monolingual and bilingual children have been taken as evidence that the two languages of bilinguals do not develop autonomously (Paradis & Genesee, 1996). Specifically, Paradis and Genesee (1996) suggest that differences between monolinguals and bilinguals, either in rate or pattern of development, may be a consequence of the systemic influence of one language on the other and, consequently, evidence for an interaction between the two languages. Support for differentiated representation with interdependent development comes from investigations of acquisition of syntax (Döpke, 2000; Hulk, 1997; Hulk & Müller 2000; Hulk & Van der Linden, 1998; Müller, 1998; Paradis, 1996). The difference between English-learning and bilingual 4-year-olds in this study argues for interactions between the languages of developing bilinguals – interactions that result in somewhat different rates of development in bilinguals in comparison to monolinguals.

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[7] A caveat is in order here. Although the simultaneous bilingual adults were not significantly different from the English adults, neither were they different from the French adults.

[8] It is possible that subtle phonetic differences in English /ð/ produced by monolingual and bilingual children may be revealed in an acoustic analysis of the productions by these children. However, their productions were not different perceptually.

To summarize, we investigated how phonetic discrimination skills are shaped by age and language experience in monolingual and bilingual 4-year-olds who are acquiring English and/or French and we compared results with previous data on infants and adults. All subjects were tested using identical stimuli and instrumentation and the same basic testing procedure. Our findings indicate that language experience facilitates perception of the English /d - ð/ contrast in both monolingual learners and bilingual learners of English. This facilitative effect is evident by 4 years of age in children who are acquiring English as monolinguals, but appears to emerge later when English is acquired simultaneously with French. We offer several possible explanations for this facilitation effect, which contrasts with developmental patterns observed in previous cross-language studies of phonetic perception. The mechanisms underlying the facilitative effects of language experience and the reasons for this delayed emergence of facilitative effects in bilingual acquisition are important directions for future research.

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