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Effect of lexical status on children's and adults' perception of native and non-native vowels

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The purpose of this study was to identify possible age-related changes in vowel perception and to assess lexical influences on both children's and adults' perception. More specifically, we sought to evaluate two proposals regarding the development of speech categories — namely, the category expansion and category definition hypotheses (e.g., Flege, 1992). In Experiment 1, 5-yr-old, 9-yr-old and adult monolingual, native speakers of English identified vowels from two synthetic continua in the nonword context /h_b/. Vowels on the "native" continuum ranged from English /ɪ/ to /i/; those on the "foreign" continuum ranged from English /ɪ/ to an unfamilar, foreign vowel /ʏ/. Young children's phoneme boundary extended further away from the /ɪ/ endpoint on the foreign continuum than did older children's and adults' — a result opposite to that predicted by the category expansion hypothesis. However, in support of the category definition hypothesis, an age-related increase in the slopes of subjects' identification functions was observed, especially for the native continuum. In Experiment 2, the same vowel stimuli were presented in the contexts /b_b/ and /b_p/ to 5-yr-olds, 9-yr-olds and adults; thus, one endpoint for the native /ɪ–i/ continua always formed a word (viz, "bib" or "beep"), whereas, for the foreign /ɪ–Y/ continua, the only word endpoint was "bib". It was again found that young children's phoneme boundary extended further away from the /ɪ/ endpoint, when this vowel was not bounded by another native vowel. In addition, the slopes of their identification functions were steeper, and thus more like those of older listeners, especially when the endpoint stimuli were real words. The results suggest that despite similarities in the extent of native vowel categories for young and older listeners, young children's categories are still quite flexible. Moreover, developmental differences in how sharply defined category boundaries are may depend, in part, on variations in lexical knowledge. © 1999 Academic Press

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1. Introduction

This study assessed monolingual, English-speaking children's and adults' identification of native and non-native vowels in word and nonword contexts. The overall purpose was to help document more fully developmental trends in the perception of vowel information and to determine whether or not children's perception is influenced by lexical status.

1.1. *Phonetic perception in infancy and childhood*

Much of what we know about the development of speech perception comes from studies of infants and there is a conspicuous gap in our knowledge about perception in childhood (see Walley, 1993*a*; Walley & Michela, 1996). As noted by Bornstein (1992), there are several reasons why the study of perceptual development, including the development of speech perception, is virtually synonymous with studies of infancy. First, the study of perception has been driven by the nature–nurture debate, and the study of infants with little experience in the world provides a portrait of those perceptual abilities given by nature. Second, methodological advances over the past 30 years have allowed researchers to pose some very sophisticated questions of preverbal infants; these investigations have, on the whole, yielded positive findings, and as infants have been shown to possess various perceptual competencies, empirical and theoretical attention has turned to ever younger ages. Third, beyond infancy, higher-level cognitive factors (including language and memory strategies) play an increasing role in perceptual performance, "… and so distinguishing perceptual processes *per se* from cognitive ones becomes problematic" (p. 173). We might even go so far as to say that some view perception as being "contaminated" by these factors.

What information has resulted from this focus on infant speech perception and what do we need to know about perception in childhood? One well-established finding is that early phonetic development entails a shift from a language-general to a language-specific pattern of perception (e.g., Werker & Tees, 1984; Polka & Werker, 1994; for review, see Jusczyk, 1997). That is, infants are sensitive at the outset to a wide variety of phonological structures, and then sometime over the first year of life, sensitivity to many non-native sounds declines. Some have attributed this decline to the acquisition of word meaning and the advent of contrastive phonology around 9–12 months of age (e.g., Jusczyk, 1993; Werker & Desjardins, 1995). Others have attributed the decline to more passive, automatic processes, because there is evidence for native language prototype by as early as 6 months of age (Kuhl, Williams, Lacerda, Stevens & Lindblom, 1992). These prototypes appear to act as perceptual magnets, rendering discrimination of good category exemplars near to the prototype poorer than that for more distant exemplars at the category boundary.

In any event, the bulk of the infant research suggests that much of the perceptual apparatus relevant to processing the native language is well in place by 1 yr of age, whereas much of that relevant to processing non-native sounds has dissipated, and tends to leave one with the impression that little, if anything happens by way of perceptual development beyond infancy. However, because language-specific influences on perception are evident in the first year, this does not mean that they are complete; some openness or plasticity certainly extends beyond this age, since individuals can learn to speak a second language authentically at least up until about 7 yr of age (see below). Yet there is little direct evidence from children on this issue. There is also little evidence relating infants' perceptual abilities to spoken language processing in childhood (see Walley, 1993*b*).

Especially little is known about vowel perception in childhood, perhaps because children seem to learn to produce many of the vowels of their native language more readily than they do its consonants (cf. Davis & MacNeilage, 1990; Otomo & Stoel-Gammon, 1992; Owens, 1996, p. 95; Stoel-Gammon & Menn, 1997, p. 107). In fact, recent evidence suggests that infants' ability to discriminate non-native vowel contrasts declines earlier than it does for non-native consonant contrasts (see Werker & Desjardins, 1995). However, because young children can produce vowels (or consonants) accurately, this does not necessarily mean that their perceptual representations are equivalent to adults'. Nor do discrimination data from infants imply adult-like representations (see Aslin, Pisoni & Jusczyk, 1983). Indeed, the few existing developmental studies of vowel perception beyond infancy point to extant differences between children and adults.

In one study, Murphy, Shea & Aslin (1989) found that 3-yr-olds identified a pair of synthetic vowels (/ae/ and /ʌ/) nearly as well as adults; yet when portions of the vowels were removed, children's performance was especially impeded, indicating that dynamic spectral change information may be particularly crucial in the development of vowel perception (see also Parnell & Amerman, 1978). More recently however, Ohde, Haley & McMahon (1996) examined identification of /i/, /a/ and /u/ in synthetic consonant–vowel syllables with and without formant transition motion and found that the performance of children (aged 5–11 yrs) was more influenced than adults' by stimulus duration, as well as consonantal context; no differential effect of formant transition motion as a function of age was observed. It was suggested that developmental effects of duration cues may be restricted to vowel as opposed to consonant perception (cf. Ohde, Haley, Vorperian & McMahon, 1995) and that the processing of vowels in a continuous mode may develop more gradually than the categorical perception of consonants.

The greater context-dependent nature of children's *vs.* adults' perception is better documented for consonants. For example, Nittrouer & Studdert-Kennedy (1987) found that 3-, 4- and 5-yr-olds' identifications of syllable-initial fricatives from a synthetic /s-š/ continuum were more influenced by vocalic transitions than 7-yr-olds' and adults'; these older subjects were more sensitive to the frequency information in the fricative noise (see also Morrongiello, Robson, Best & Clifton, 1984; Nittrouer, 1992). (In a follow-up production study, spectral differentiation of /s/ *vs.* /š/ increased with age, while the impact of vocalic context, or coarticulation effects, decreased (Nittrouer, Studdert-Kennedy & McGowan, 1989; see also Ohde, 1994). Similarly, Krause (1982) found that 3-yr-olds needed a larger difference than adults in preceding vowel length to identify stimuli ending in voiced and voiceless stops, and others have observed that young children pay particular attention to formant transitions in judging place of stop consonant articulation (e.g., Ohde et al., 1995; Walley & Carell, 1983). A corollary finding in these and other studies is that consonant perception by children up to about 5 or 6 yrs of age appears less categorical than perception by adults; specifically, the slopes of children's identification functions for various stimulus continua are shallower than adults' (see also Wolf, 1973; Zlatin & Koenigsknecht, 1975; Simon & Fourcin, 1978; Burnham, Earnshaw & Clark, 1991; Kuipers, 1996).

Together, these studies suggest that young children's perceptual representations for both vowels and consonants are not yet adult-like, i.e., their representations are not as fine-gained or segmental, and are instead more holistic in nature or based to a greater extent on information distributed throughout the speech waveform. Indeed, there is a growing consensus that the phoneme emerges only gradually as a unit of speech representation/processing in early through middle childhood with increased exposure to one's native language and with spoken vocabulary growth (see Fowler, 1991; Walley, 1993*b*; Nittrouer, 1996). This position contradicts the traditional view, according to which phonemic segments are present and functional in infancy, but only become accessible for conscious inspection with substantial reading exposure (e.g., Gleitman & Rozin, 1977; Liberman, Shankweiler & Liberman, 1989; for elaboration of these positions and additional references, see Metsala & Walley, 1998). However, definite empirical evidence on what prompts the emergence of the segment is still lacking. For example, there have been few systematic developmental studies of how perception is influenced by lexical status or familiarity (but see Garlock, 1997; Metsala, 1997). In addition, there have been no studies on how vowel identification functions might change with age. Therefore, although it is well-established that adults' perception (identification and discrimination) of vowels is less categorical than that of consonants (e.g., Pisoni, 1973), and although children's perception of consonants appears less categorical than adults' (at least in terms of the slopes of their identification functions; see references above),[1] we do not know whether vowel identification functions, like those for consonants, become increasingly steep with development, and if so, precisely when this change occurs.

1.2. *Phonetic perception and second language learning*

Our need to know more about native language perception, including vowel perception, in childhood provides one point of entry to the present study. Another point of entry derives from studies of second language learning. Adults and older children who learn a second language (L2) often fail to negotiate cross-language vowel and consonant differences, and thus perceive and produce L2 sounds inaccurately (see Flege, 1992; cf. Pisoni, Lively & Logan, 1994). For example, many adult native speakers of Spanish, which lacks an /ɪ/ phoneme, do not distinguish English /i/ and /ɪ/ in perception or production (e.g., Flege, Bohn & Jang, 1997). Munro, Flege & MacKay (1996) examined the production of English vowels by 240 Italian adults, who had begun learning English at various ages (2–23 yrs) when they moved to Canada, but all of whom had spoken English for at least 15 years. As age of first exposure to English increased, the proportion of subjects judged by native English listeners to have produced the English vowels with a foreign accent increased systematically. In some cases, foreign accent was evident for vowels spoken by subjects who began learning English as early as 7 yr of age (see also Flege & Fletcher, 1992).

One possible explanation of these results regarding the timing of L2 learning is that as acquisition of the native or first language (L1) proceeds, individuals become increasingly likely to identify L2 sounds in terms of the phonetic categories of the L1. Flege (1992), for example, has proposed that as the phonetic system of the L1 develops and stabilizes in early through middle childhood, it is more difficult to establish new phonetic categories. More specifically, he outlines two (not mutually exclusive) hypotheses about changes in the categories comprising children's L1 phonetic system that impact L2 learning:

[1] Strictly speaking, both discrimination and identification data may be necessary for making inferences about categorical perception (Burnham, Earnshaw & Quinn, 1987; Studdert-Kennedy, Liberman, Harris & Cooper, 1970), but most developmental studies have not obtained these two types of data (cf. Burnham et al., 1991).

(1) a "category definition" hypothesis, according to which the core acoustic properties of exemplars of each phonetic category, and the weighting of these properties, become better defined with age; and (2) a "category expansion" hypothesis, according to which the range of phones that may be identified as instances of a given L1 category increases. Thus, as more of what is initially uncommitted vowel space becomes devoted to the L1, the formation of new vowel categories is more difficult. Perhaps then those who learn an L2 late (after L1 acquisition is well underway) tend to perceive and produce L2 vowels inaccurately because they are less likely than early learners to attend to phonetic differences between vowels in the L1 and L2, and L2 vowels are instead identified as distorted exemplars of L1 categories.

In support of the category definition hypothesis, the slopes of young children's phonetic identification functions are not as steep as those of older children and adults (see references above), indicating that fewer stimuli are consistently judged as belonging to one phonetic category or another. However, as noted previously, we do not know whether this finding applies to vowels. In support of the category expansion hypothesis, Flege & Eefting (1986) observed that with age, native English listeners identified a wider range of stimuli on a voice-onset time continuum as /d/. Bond & Ademescu (1979) found that native English 11- to 13-yr-olds were less able than 4-yr-olds to differentially identify English egressive stops and Hausa implosive stops with the same place of articulation, perhaps because the older children's representations for stops were more broadly tuned and were thus likely to encompass the unfamiliar, Hausa stops. In a study by Shimizu & Dantsuji (1983), Japanese 5-yr-olds, but not adults showed a peak in correct discrimination of /r/ and /l/ near the English phoneme boundary — a result that would be expected if the adults' Japanese /R/ (a liquid with characteristics of both English /r/ and /l/) were more broadly tuned than children's. To our knowledge, the only previous vowel perception study bearing on the category expansion hypothesis is that of Butcher (1976), who found that various cardinal vowels were perceived as more similar when they occupied crowded *vs.* uncrowded portions of adult and child listeners' L1 vowel space (English, French or German). Moreover, adults tended to perceive these vowels as more similar than did children (e.g., native English adults judged French /y/ to be more similar to English /u/), suggesting that their vowel space is "filled" to a greater extent than children's and thus that their native vowel categories are more likely to encompass L2 vowels.

In the present study, we were interested in further assessing the category definition and expansion hypotheses. More generally, we wanted to document possible age-related changes in vowel perception, and to learn more about how such changes might contribute to the emergence of foreign accent, as well as difficulties in L2 perception. In Experiment 1, 5-yr-olds, 9-yr-olds and adults were asked to identify stimuli from two vowel continua — a "native" one ranging from English /ɪ/ to /i/ and a "foreign" one ranging from English /ɪ/ to a non-English vowel /Y/ — in a nonword context. We asked whether there are age-related increases in the steepness of vowel identification slopes, as predicted by the category definition hypothesis, and whether there are age-related increases in the range of stimuli identified as English /ɪ/ on the foreign continuum, as predicted by the category expansion hypothesis.

In Experiment 2, 5-yr-olds, 9-yr-olds and adults were presented with the same vowel stimuli in both words and nonword contexts. It is fairly well-documented that phoneme perception by adults is influenced by lexical status. For example, when presented with stimuli from voice-onset-time continua ranging from "dash" to "tash" and from "dask" to "task", adults make more identification responses that are consistent with the endpoint that is a word (e.g., Ganong, 1980; for review, see Pitt & Samuel, 1993). However, in most existing developmental studies there has been no systematic manipulation of stimulus lexicality. Thus, we know little about phonetic–lexical interactions in children and about how such interactions might vary as a function of age. According to the emergent view of phoneme development described previously (e.g., Fowler, 1991; Walley, 1993*b*), we might expect young children to perform more like older listeners when the stimuli to be identified are real words (e.g., for their identification slopes to be steeper). The results of Experiments 1 and 2 should therefore help to fill both empirical and theoretical gaps in what is known about the development of vowel perception beyond infancy and about perception as speech patterns assume meaning — whether this involves age-related changes and/or constancies.

2. Experiment 1

We focused on the performance of 5-yr-old *vs.* 9-yr-old children (*vs.* adults) for three reasons. First, most research on speech perception in childhood has involved similar age comparisons (see Walley, 1993*b*). Second, other research has shown that 7 yrs of age represents an important watershed with respect to whether or not one is able to learn to speak a second language authentically (see Flege, 1992) and our child subjects fall on either side of this demarcation point. Third, the results of preliminary work with children aged 4–12 yrs suggested that important changes might be occurring between the ages of 5 and 9 yrs (Walley, Flege & Randazza, 1993).

Two vowel continua — a "native" and a "foreign" one — were synthesized and presented in the context /h_b/. This context was selected because it yielded nonword stimuli that might be considered more natural than isolated vowels. The native continuum ranged from English /ɪ/ to /i/; the foreign continuum ranged from English /ɪ/ to a front rounded vowel not found in English, which we have symbolized as /Y/. Subjects were trained to identify the endpoints of a given continuum before completing a two-alternative forced choice identification test.

The category definition hypothesis was assessed by examining the slopes of subjects' identification functions. Shallow functions typically indicate inconsistent or uncertain labeling in the vicinity of phoneme boundaries. Therefore, this hypothesis would be supported if slopes were to become increasingly steep with age, perhaps especially for the foreign continuum. The category expansion hypothesis was assessed by examining the location of phoneme boundaries. By this hypothesis, there should be a shift in the phoneme boundary away from the /ɪ/ endpoint on the foreign *vs.* native continuum, especially for older listeners. (For the native continuum, the location of the /ɪ/-/i/ boundary was not expected to vary greatly with age, since the /ɪ/ category was bounded by another native vowel.)

2.1. *Method*

2.1.1. *Subjects*

Each of our three subject groups consisted of 14 monolingual speakers of American English with no history of speech or language impairment. Children were recruited from schools and pre-schools near the University of Alabama at Birmingham (UAB) through letters sent home to parents; the adults were UAB undergraduates.

The mean age of the younger children was 5-yrs, 1 month (range = 4,4–6,2), the mean of the older children was 9-yrs, 1 month (range = 8,4–10,1; 8 males and 6 females in each group). All 5-yr-olds were native Alabamians, as were both parents of all but 1 child. Eleven of the 9-yr-olds were native Alabamians, the remaining 3 had resided in Birmingham over half their lives. Both parents of these children were native Alabamians, except those of 1 child. The mean age of the adults was 23-yrs, 8 months (range = 21,6–27,2; 7 males and 7 females). Twelve were native Alabamians; the others had lived in Birmingham for at least two years. Thus, in contrast to many other developmental studies, our subjects comprised a well-defined and uniform sample with respect to dialect background.

Seven additional younger children were tested, but excluded because they failed a pure-tone hearing screening at octave frequencies between 500 and 4000 Hz, failed to meet criterion responding during training, or declined to continue participating.

2.1.2. *Stimuli*

Two vowel continua — a native one ranging from English /ɪ/ to /i/, and a foreign one ranging from English /ɪ/ to non-English /Y/ — were created using a version of Klatt's (1980) formant synthesizer. The 8 stimuli in each continuum began with /h/ and ended with /b/. The duration of the /h/ frication noise was 110 ms, followed by 205 ms of steady-state vowel, formant transitions into /b/ lasting 30 ms, and then a 70 ms closure interval (half of which was voiced). Each stimulus ended with a natural release burst spoken by an adult male. The stimuli were RMS-normalized to equalize for intensity before the addition of the burst.

Fig. 1 shows the location of our stimuli in the vowel space. For both continua, F1 varied in equal steps from 473 mels (for the /ɪ/ endpoint) to 340 mels (for the /i/ and /Y/ endpoints). F2 also varied in equal mel steps for both continua; however, whereas F2 *increased* from 1501 to 1725 mels on the /ɪ/-/i/ continuum, it *decreased* from 1501 to 1277 mels on the /ɪ/-/Y/ continuum. (The F1 and F2 values, in Hz, of the stimuli were 388 and 1830 for the /ɪ/ endpoint, 266 and 2306 for the /i/ endpoint, and 266 and 1423 for the /Y/ endpoint.) Thus, the /ɪ/-/i/ and /ɪ/-/Y/ continua were mirror images of one another in that F1 values increased by the same amount for both continua, and F2 values increased or decreased by the same amount along the two continua. For all stimuli, F0 fell linearly from 125 to 92 Hz over the steady-state portion. The mel values of F3, F4 and F5 were 2004, 2104 and 2278 (3010, 3300 and 3850 Hz), respectively; the bandwidths for F1, F2, F3, F4 and F5 were 60, 80, 110, 250 and 200 Hz, respectively (after Kuhl, 1991).

2.1.3. *Selection of* /ɪ/, /i/ *and* /Y/

The F1 and F2 values of our /ɪ/ endpoint were based on goodness ratings collected from monolingual, American-English speakers (native Alabamians and/or listeners with expertise in phonetics) in two pilot studies. In the first pilot, 8 listeners rated a 5×5 matrix of /hVb/ stimuli in which F1 ranged from 340 to 556 mels (310–470 Hz), F2 from 1424 to 1655 mels (1830–2149 Hz). The best rating was given to the stimulus with an F1 value of 473 mels (388 Hz) and an F2 value of 1501 mels (1830 Hz). Since this stimulus had the lowest F2 value in the matrix, this matrix may not have been adequate to define the optimal F2 value for /ɪ/. Therefore, a second matrix with lower F2 values was

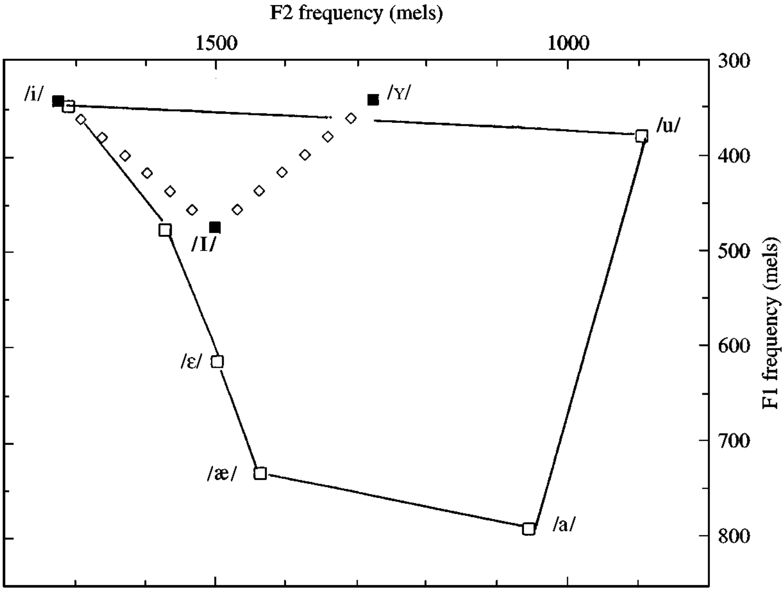

Figure 1. F1 and F2 values of the stimuli comprising the synthetic /ɪ-i/ and /ɪ-Y/ continua used in the present study. Also shown are the mean values for various vowels spoken by male native speakers of American English (from Peterson & Barney, 1952). □ mean Peterson and Barney (1952) values; ■ continuum endpoints; ◇ stimuli in /ɪ-i/ and /ɪ-Y/ continua.

constructed and the stimuli presented to 10 listeners. As before, the best rating was given to the stimulus with an F1 of 473 mels and an F2 of 1501 mels. Therefore, this stimulus was selected as the /ɪ/ endpoint.[2]

The F1 and F2 values of our /i/ endpoint were based on those of Kuhl (1991).

As noted above, the foreign continuum was constructed to be symmetrical with the native one in terms of F1 and F2 changes. Thus, our /Y/ endpoint occurs in a portion of the vowel space that is not systematically exploited by English, but is used by languages such as German and Swedish; however, it was not selected as an especially good token of any vowel from these languages — it was simply the mirror image of the /i/ one.[3] Most importantly, it sounded distinctively "foreign".

[2]This stimulus has a slightly lower F2 value than the average /ɪ/ value for male native speakers of English reported by Peterson & Barney (1952; see Figure 1). This difference might be due to specific parameters of our synthetic stimuli, such as the fixed frequencies of F3–F5 or the absence of formant movement. A more interesting possibility is that /ɪ/ is shifting, at least for Southern dialect. One recent change in Birmingham, according to Labov & Ash (1997), is raising and dipthongization of /ɪ/ to /iə/. However, whereas our pilot listeners' ratings were influenced by variations in F1 frequency, which correspond roughly to differences in vowel height, they were unaffected by changes in F2, which correspond to differences in the front–back dimension. Also, our /ɪ/ endpoint received the best goodness ratings in both pilots, despite the difference in the F2 frequency range of the stimulus matrices.

[3]Traditionally, the symbol /Y/ designates the high front rounded counterpart of /ɪ/. We used this symbol for our foreign endpoint, because its F1 and F2 frequency values are somewhat closer to those published for /Y/ vs. /y/ vowels of languages such as German and Swedish (e.g., Kuhl et al., 1992; Polka & Werker, 1994); however, our endpoint is higher and further back in the vowel space than German /Y/, for example (e.g., Iivonen, 1987). Also, the F3 for our /Y/ endpoint was the one used by Kuhl (1991) for a good English /i/, and thus higher than that for German /Y/. To have obtained optimal high front rounded vowels would have required changing the frequencies of both F2 and F3 (Stevens, Liberman, Studdert-Kennedy & Öhman, 1969).

2.1.4. *Procedure*

Subjects were tested individually in a quiet room in a single session lasting 30–60 min. The stimuli were recorded on audio tape (Marantz Model PMD420) for binaural presentation over headphones (Denon Model AH-D100) at a comfortable listening level. Two tapes, each with 50 randomized tokens of the endpoint stimuli from either the native or foreign continuum, were used for training. Two additional tapes, each with seven randomized blocks of the eight stimuli from a given continuum, were used for identification testing. The inter-stimulus interval for all tapes was 3.0 s.

Each subject was tested on both the native and foreign continua, with order counterbalanced across subjects in each age group. In training, subjects were told that they would hear two kinds of pretend words, and asked to push one button when they heard "hib" and another button when they heard "the other pretend word". (These response alternatives were employed in order to maintain consistency in task format and response requirements for within-subject testing on the two continua and to avoid requiring the experimenter to authentically produce the non-native /Y/ endpoint.) The two buttons were associated with different-colored and -shaped geometric labels. The same button assignment was used across continua for a given subject (e.g., the left button and same label for "hib", the right button, but different labels for the /i/ and /Y/ endpoints); button assignment was counterbalanced across subjects in each group. Verbal feedback was given by the experimenter after each response.

The criterion for advancement to testing was 9/10 consecutive correct responses for endpoint stimuli. Additional training was given to some children. At the beginning of testing, subjects were told that they would hear more examples of "hib" and "the other pretend word", and to continue pressing one of the two buttons to indicate what they had heard. Responses were recorded by the experimenter on a score sheet that indicated the correct response for endpoint stimuli (for which verbal feedback was given), but did not reveal the identity of other continuum members (for which no specific feedback was given, only general encouragement). (The experimenter was able to detect the presentation of a stimulus by monitoring the tape recorder's VU meter, but was unable to hear the stimuli.) The experimenter typically paused the tape during testing for younger subjects, because they responded more slowly than older ones and required greater social interaction to stay on-task. Children were awarded stickers after each block of test trials, and all subjects were given a short break between training/testing for the two continua.

2.2. *Results*

2.2.1. *Training*

Trials-to-criterion scores were submitted to a (3) Age $\times$ (2) Continuum ANOVA for a mixed (between-subjects, within-subjects) design, which revealed only a main effect of age [$F(2, 39) = 4.54$, $p < 0.025$]. *Post-hoc* Tukey's tests ($\alpha = 0.05$) indicated that 5-yr-olds required more training trials ($M = 15.4$) than both 9-yr-olds and adults ($M = 10.6$ and 10.4). Across age, a similar number of trials was needed to reach criterion for the native and foreign continua ($M = 12.7$ and 11.5).

2.2.2. *Identification of endpoint stimuli in testing*

Mean /ɪ/ responses for each of the 8 stimuli on the native and foreign continua are shown in Fig. 2 as a function of age. (Responses are expressed as proportions to facilitate comparison with the results of Experiment 2.)

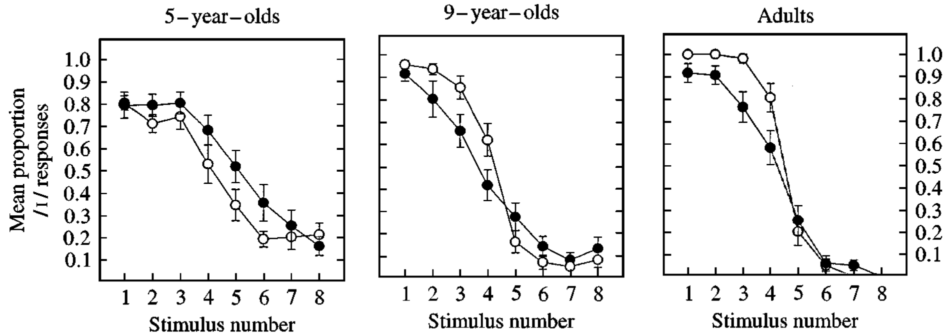

Figure 2. Mean identification functions for the native (/ɪ-i/) and foreign (/ɪ-Y/) continua for children and adults in Experiment 1. Stimulus 1 corresponds to the /ɪ/ endpoint, stimulus 8 to either the /i/ or /Y/ endpoint. ○ native continuum; ● foreign continuum.

Total correct responses for the /ɪ/ and /i/ or /Y/ endpoint stimuli (maximum possible score = 14) were examined to assess whether the effects of training persisted and subjects were "on task". A (3) Age × (2) Continuum ANOVA of these responses (/ɪ/ plus not-/ɪ/) revealed only a main effect of age [$F(2, 39) = 15.69$, $p < 0.001$]; 5-yr-olds made fewer correct responses than both 9-yr-olds and adults, whose performance did not differ ($M = 11.3$ *vs.* 12.8 and 13.7; mean proportions = 0.81 *vs.* 0.91 and 0.98), perhaps reflecting greater uncertainty regarding intermediate stimulus types. Nevertheless, young children's performance was quite good in absolute terms and well above chance. Across age, correct responses for the native and foreign continua were similar (M = 12.8 and 12.5).[4]

During training and testing, the experimenter did not explicitly label the non-/ɪ/ endpoints for the reasons outlined earlier. However, some subjects, especially children, spontaneously named the endpoints of our continua during testing. Therefore, as the experiment progressed, we decided to ask subjects "to say the sound they had heard" after testing on each continuum and transcribed their responses. First, producing the intended native /ɪ/-/i/ contrast seemed fairly straightforward at all age levels and/or was easy to remember. Second, producing the /ɪ/ target after listening to the foreign continuum was also straightforward, but productions of "the other sound(s) heard" (the /Y/ endpoint) were more varied; some subjects produced the vowel /i/ (perhaps because of limitations on production repertoire and/or because some had been tested on the native continuum first), but very seldom did they produce any other native vowel, and some produced /Y/ authentically. Therefore, it is unlikely that the foreign endpoint was consistently perceived as a native vowel. Finally, adults were more likely than children to note that they had heard more than two sounds for each continuum and to offer a description. These admittedly informal observations attest to the appropriateness of our /ɪ/ and non-/ɪ/ endpoints (cf. footnotes 2 and 3).

[4] Separate AVOVAs for each continuum of correct /ɪ/ *vs.* not-/ɪ/ responses yielded main effects of age consistent with this overall analysis, except that for the foreign continuum, only the 5-yr-old *vs.* adult comparison was significant, i.e., subjects did not respond differentially or for /ɪ/ *vs.* /i/ or for /ɪ/ *vs.* /Y/, and endpoint identity did not interact with age.

2.2.3. *Phoneme boundary locations and slopes*

By the category expansion hypothesis, the /ɪ/ category should encompass a wider range of variants with increasing age, at least on the foreign continuum, where /ɪ/ is not bounded by another native vowel. In order to evaluate this prediction, we calculated phoneme boundary locations using probit analysis (i.e., based on the 50% intercept of cumulative normal curves fit to each subject's identification function for a given continuum; after Best & Strange, 1992). A (3) Age $\times$ (2) Continuum ANOVA of phoneme boundary scores revealed no main effects, but a significant Age $\times$ Continuum interaction [$F(2, 35) = 4.59 < 0.025$).[5] For 5-yr-olds, mean boundaries on the native and foreign continua were 4.33 and 5.29; for 9-yr-olds, mean boundaries were 4.24 and 4.01; for adults, mean boundaries were 4.51 and 4.11 (see Fig. 2). The interaction obtained because the boundaries of 5-yr-olds for the two continua differed, whereas those of older listeners did not, and because for the foreign continuum, younger subjects' boundary extended further away from the /ɪ/ endpoint than the boundaries of 9-yr-olds and adults. This result is the opposite of that predicted by the category expansion hypothesis.

By the category definition hypothesis, we would expect identification functions to become steeper with age, as Fig. 2 suggests. To evaluate this prediction, the slope of each subject's function for a given continuum was calculated as the reciprocal of the standard deviation of the ogives obtained from probit analysis (Best & Strange, 1992). An ANOVA of these scores yielded main effects of age [$F(2, 35) = 29.37$, $p < 0.001$], continuum [$F(1, 35) = 8.43$, $p < 0.01$) and an Age $\times$ Continuum interaction [$F(2, 35) = 4.52$, $p < 0.025$). For 5-yr-olds, mean slopes for the native and foreign continua were 0.35 and 0.38; for 9-yr-olds, mean slopes were 0.82 and 0.68; for adults, mean slopes were 1.39 and 0.96. For the native continuum, all age comparisons were significant — i.e., the slopes of adults' identification functions were steeper than 9-yr-olds', which were steeper than 5-yr-olds'; for the foreign continuum, adults' and 9-yr-olds' slopes were similar, and both were steeper than 5-yr-olds'; the native *vs.* foreign comparison was significant only for adults. In sum, the slopes of subjects' identification functions became increasingly steep with age, especially for the native continuum.

2.3. *Discussion*

In this experiment, 5-yr-olds, 9-yr-olds and adults identified stimuli ranging from /ɪ/ to /i/ and from /ɪ/ to a non-native vowel /Y/. We found no support for the category expansion hypothesis. In particular, when /ɪ/ was contrasted with /Y/, the location of subjects' phoneme boundary did not shift away from the native vowel with age. Instead, 5-yr-olds' phoneme boundary extended further away from the /ɪ/ endpoint than 9-yr-olds' and adults' on the foreign continuum; i.e., when a native vowel was contrasted with a foreign one, young listeners were more likely to identify the foreign vowel as a familiar, native one.

Analysis of the slopes of subjects' vowel identification functions revealed an Age $\times$ Continuum interaction, as predicted by the category definition hypothesis. Specifically, 5-yr-olds' slopes were similar for the native and foreign continua, and became steeper

[5] For the native continuum, the identification function of one adult had no 50% cross-over point within our stimulus range, for the foreign continuum, the functions of one 5-yr-old and one 9-yr-old were grossly nonmonotonic and that of one adult had no cross-over. The 4/84 (5%) missing boundary (and slope) scores were replaced (and degrees of freedom adjusted) using a method that assumes additivity of subject and treatment effects and thus minimizes interaction effects (Winer, Brown & Michels, 1991, pp. 480, 481).

with age, especially for the native continuum. (In other words, older listeners seemed most sure of the /ɪ/-/i/ contrast.) This result is also consistent with proposals regarding the increasingly segmental nature of speech representation over childhood (e.g., Fowler, 1991; Walley, 1993*b*; Nittrouer, 1996) and with empirical findings of age-related changes in consonant perception (e.g., Burnham et al., Nittrouer, 1992; Kuipers, 1996). Our finding might not reflect real developmental differences in basic speech processing ability, but perhaps it merely reflects attentional differences across age. After all, our youngest subjects did not identify endpoint stimuli as well as older subjects in testing (see also Krause, 1982; Burnham et al., 1991; Kuipers, 1996), despite having received feedback and extra training. However, such potential attentional differences are not trivial or uninteresting (see General Discussion).

These results help to provide a more sensitive picture of age-related trends in vowel perception. That is, it would seem that any age-related boundary differences are quite subtle, whereas slope differences are more marked. In our view, these differences are not the result of simple attentional differences, since, for example, even 9-yr-olds, whose training experience was most similar to adults' and who performed as well on endpoints in testing as adults, still displayed shallower slopes than adults for the native, but not the foreign continuum. Still, our identification task does seem to have been fairly difficult for young children, as indicated by their higher drop-our rate, their need for more trials to reach criterion in training, and the fact that they never identified endpoints as well as adults in testing (although none of these findings is particularly unusual for studies with similar-aged children). It seems unlikely that this difficulty was the result of our having employed inappropriate endpoint stimuli, since many subjects (both young and old) were able to produce a contrast that was consistent with the intended one. Rather, we suspect that this difficulty was largely a result of having to identify the vowel stimuli in a non-word context — a possibility assessed in Experiment 2.

3. Experiment 2

This experiment examined the effect of lexical status on children's and adults' identification of the same vowel stimuli as those used in Experiment 1.

Many developmental studies on speech perception have employed only very simple (e.g., consonant–vowel) stimuli which are typically presented to children in a game format in order to enhance overall task comprehension and maintain attention. For example, children are often asked to learn speech stimuli as the labels for pictured objects or as the names of puppets — whether or not the stimuli actually correspond to real words or names (e.g., Krause, 1982; Walley & Carrell, 1983; Ohde et al., 1996). That is, stimulus lexicality and/or extent of word familiarity have rarely been systematically controlled in such studies and no previous study has, to our knowledge, manipulated and assessed the impact of lexical status on young children's perception at a phonetic level (cf. Reed, 1989). In contrast, there have been numerous studies with adults showing, for example, that phoneme (consonant) boundary locations are influenced by the lexical status of continuum endpoints (for review, see Pitt & Samuel, 1993); specifically, when one endpoint constitutes a word, adult listeners are more likely to identify stimuli on the continuum in terms of that endpoint, or the phoneme boundary shifts away from the word endpoint.

What might we expect about the impact of lexical status on children's perception? According to recent models of spoken word recognition in children learning a first language (Fowler, 1991; Nittrouer, 1996; Metsala & Walley, 1998), speech representations become increasingly segmental in structure over early through middle childhood — primarily as a result of vocabulary growth, and it is this change that provides the foundation for more explicit segmentation ability or phonological awareness. In support, children's perception of lexical items varies with measures of word familiarity, such that children are better at detecting mispronunciations in early- *vs.* later- acquired words (e.g., Walley & Metsala, 1990), and phonological awareness in normal and dyslexic children is better for familiar *vs.* unfamiliar words that have more complete underlying phonological representations (e.g., Swann & Goswami, 1997). By these models, we would also expect children's perception to be enhanced for vowels in familiar word, as opposed to unfamiliar nonword contexts. We assessed this general expectation by testing 5-yr-olds, 9-yr-olds and adults in one of the two conditions — native or foreign.

In the native condition, the stimuli of our /ɪ/-/i/ continuum were presented in the context /b_b/ or /b_p/; thus, one set of stimuli ranged from the word "bib" (/bɪb/) to the nonword "beeb" (*/bYb/), while the other set ranged from the nonword "bip" (*/bɪp/) to the word "beep" (/bip/). Two points should be noted here. First, the consonant context differs from that of Experiment I, because we wanted a very familiar word to serve as one of the endpoints for each continuum. Second, this pairing of continua is analogous to the pairings used in adult studies of lexical effects on phoneme identification, in which the perception of variations in an acoustic-phonetic cue, such as voice-onset-time (e.g., Ganong, 1980), is examined in different contexts. In the foreign condition, the stimuli of our /ɪ/-/Y/ continuum were presented in the same contexts; thus, one set of stimuli ranged from the word "bib" (/bɪb/) to the nonword "bYb" (*bYb/), while the other set ranged from the nonword "bip" (*/bɪp/) to the nonword "bYp" (*/bYp/). That is, by definition, stimuli containing the /Y/ vowel are nonwords, because they contain a foreign vowel, and there is therefore an asymmetry across our four continua in the lexical status of endpoint stimuli.

One specific expectation was that, as in previous research on adults' consonant perception (see Pitt & Samuel, 1993), we would observe a difference in phoneme boundary location, especially in the native condition, where one endpoint on each of the paired continua constitutes a word. The same effect might be apparent even for young children because our word endpoints are typically early-acquired items. However, this effect might be greater for adults who have probably heard these words more often than children; alternatively, it might be greater for children, if they rely to a greater extent on top-down, lexical information when making perceptual decisions than do adults (see also Reed, 1989). A second expectation was that the slopes of children's and adults' identification functions would be similarly steep — at least for the continua of the native condition, where each of the endpoints is a native vowel and one endpoint on either continuum occurs in the context of a familiar word. That is, such a result would be expected if vocabulary growth (e.g., in terms of increases in individual item familiarity) promotes the segmental structuring of speech representations (Fowler, 1991; Walley, 1993*b*; see also Nitrouer, 1996).

3.1. *Method*

3.1.1. *Subjects*

All subjects were native speakers of English from Alabama, who had no history of a speech or hearing disorder and who passed a hearing screening, as described for

Experiment 1.

Three groups, each with 14 subjects, were tested in the native condition: mean ages = 5 yr, 2 months (range = 4,6–6,1; 9 females, 5 males), 9,5 (8,3–10,5; 8 females, 6 males), 36 yr, 5 months (24,3–47,0; 10 females, 4 males).[6] Another five 5-yr-olds were tested, but four did not pass training and one refused to complete the experiment. The data of two other 5-yr-olds were excluded from analysis: one child's identification functions for both continua were nonmonotonic, while the other child's functions had no 50% crossover. Thus, each child had missing slope scores for both continua. For inclusion in the experiment, a subject had to contribute at least one boundary (and slope) score. (This requirement was met by all subjects in Experiment 1.)

Three groups, also with 14 subjects each, were tested in the foreign condition; mean ages = 5 yr, 8 months (4,8–6,1; 7 females, 7 males), 9,3 (8,2–10,0; 7 females, 7 males), 35,10 (27,7–43,4; 12 females, 2 males). Another six 5-yr-olds were tested, but five failed to pass training, and one refused to complete the experiment. In addition, the identification functions of five other 5-yr-olds were nonmonotonic for both continua and/or had no 50% crossover and their data were excluded. One additional 9-yr-old did not pass training, and the data of two other 9-yr-olds were excluded because their identification functions for both continua were nonmonotonic.

3.1.2. *Stimuli*

The vowel stimuli from Experiment 1 were presented in the contexts /b_b/ and (/b_p/ to form four continua: in the native condition, one continuum ranged from the word "bib" (/bɪb/) to the nonword */bib/, while the other ranged from the nonword */bɪp/ to the word "beep" (/bip/); in the foreign condition, one continuum ranged from the word "bib" (/bɪb/) to the nonword */bYb/, while the other ranged from the nonword */bɪp/ to the nonword */bYp/.[7] "Bib" and "beep" were selected as word endpoints because we anticipated that these items would be highly familiar to all subjects.

Each stimulus began with a synthetic /b/ that had 50 ms of prevoicing and 30 ms transitions, followed by 205 ms of steady-state vowel, and then by 75 ms of transitions into either a naturally produced /b/ with closure voicing and a voiced burst, or a naturally produced /p/ without closure voicing and with a voiceless release burst. All other aspects of stimulus construction were the same as those described for Experiment 1.

3.1.3. *Procedure*

Each subject was tested in either the native or foreign condition, because we judged it important to assess performance within-subjects for the two paired continua of the

[6] For each condition, half the adults were parents of our 5-yr-old subjects, half were parents of the 9-yr-olds in order to achieve even closer matching in dialect background than in Experiment 1. A a result, adults in Experiment 2 were older, and more mothers than fathers participated.

[7] Since the perception of consonant voicing can be influenced by preceding vowel duration, and *vice versa* (Whalen, 1989), we included a check to ensure that any observed differences in phoneme boundaries across continua were not solely due to the difference in the final consonant. Two additional stimuli were constructed for each condition: on the /b_b/ continuum, the vowel portion of stimulus 5 was shortened by 60 ms, on the /b_p/ continua, stimulus 4 was lengthened by 60 ms. Mid-continuum stimuli were altered because they were ambiguous with respect to vowel identity for our pilot listeners. There was no difference in the number of /ɪ/ responses made by our subjects for the changed and standard duration stimuli for both continua in either condition, suggesting that the observed boundary differences were not simply a function of the final consonant difference. The age-related differences in performance for the foreign *vs.* native condition reported in the main text are consistent with this interpretation.

native condition, as in previous studies of lexical effects on adults' phoneme identification. Thus, this aspect of the design differs from Experiment 1, where a given subject was tested on both the native and foreign vowel continua.

Otherwise, the procedure was similar to that of Experiment 1. Order of continuum presentation (/b_b/ or /b_p/ context) in each condition was counterbalanced across subjects within a given age group, as was button assignment (left or right) for subjects' identification responses. Subjects were first trained on the endpoints of a given continuum. In the native condition, they were taught to press one button when they heard /bɪb/, a second button when they heard "the other sound" (*/bib/), or one button when they heard */bɪp/, a second button when they heard "the other sound" (/bip/). For the foreign continua, they were taught to press one button when they heard /bɪb/, a second button when they heard "the other sound" (*/bYb/), or one button when they heard */bɪp/, a second button when they heard "the other sound" (*/bYp/).

As in Experiment 1, only the /ɪ/ endpoints were labeled verbally by the experimenter. However, the two response buttons associated with the word endpoints were labeled with a picture of a baby wearing a bib and a picture of a car making a beeping noise (i.e., with "beep" lines). Buttons associated with nonwords on the native and foreign continua were labeled with a uniquely colored and shaped geometric form, as in Experiment 1. However, in testing, subjects heard 10 (*vs.* only 7) repetitions of each stimulus on a given continuum in random order. Specific feedback was again given only for responses to endpoint stimuli.

After identification testing, we also collected age-of-acquisition ratings from each subject for several items spoken by the experimenter that included the words "bib" and "beep" and the nonwords */bɪp/ and */bib/ (for procedural details, see Walley & Metsala, 1992). Subjects heard the same items regardless of the condition (native or foreign) in which they had participated; i.e., the endpoints of the foreign continua were not included, so that the experimenter did not have to produce them authentically. These ratings were collected as a manipulation check — i.e., to confirm that "bib" and "beep" were indeed familiar to all subjects. Both children and adults rated the word stimuli as having been acquired earlier than the unfamiliar nonword stimuli, even subjects in the foreign condition who had not heard the latter.

3.2. *Results*

3.2.1. *Training*

For each condition, trials-to-criterion scores were submitted to a (3) Age $\times$ (2) Continuum ANOVA for a mixed design. (Separate analyses were conducted for the native and foreign conditions, because, as noted earlier, there is an inherent asymmetry in the lexical status of the continuum endpoints in the two conditions.) In the native condition, only a main effect of age was obtained [$F(2, 39 = 3.31$, $p < 0.05$]. The mean number of trials required to reach criterion by 5-yr-olds, 9-yr-olds and adults were 15.4, 12.9 and 10.4; only the 5-yr-old *vs.* adult comparison was significant, according to *post-hoc* tests. In the foreign condition too, only a main effect of age was obtained [$F(2, 39) = 19.14$, $p < 0.001$]. The mean numbers of trials required to reach criterion by 5-yr-olds, 9-yr-olds and adults were 22.9, 13.6 and 10.7; 5-yr-olds required more trials to reach criterion than both groups of older subjects. Across age, similar numbers of trials were needed to reach criterion for the /b_b/ and /b_p/ continua in the native condition (12.1 and 13.6) and in the foreign condition (14.8 and 16.7).

3.2.2. *Identification of endpoint stimuli in testing*

Mean /ɪ/ responses (in proportions) for each of the stimuli on the two continua of the native condition are shown in Fig. 3 as a function of age, those for the foreign condition are shown in Fig. 4.

For the native condition, a (3) Age × (2) Continuum × 2 (Endpoint; /ɪ/ *vs.* non-/ɪ/) ANOVA of correct responses for endpoint stimuli (maximum possible score = 10) revealed a main effect of age [$F(2, 39) = 8.25$, $p < 0.001$]. Mean correct responses by 5-yr-olds, 9-yr-olds and adults were 8.9, 9.4 and 9.8; only the 5-yr-old *vs.* adult comparison was significant. A main effect of continuum was also found [$F(1, 39) = 4.36$, $p < 0.05$]. Mean correct responses were lower for the /b_b/ *vs.* /b_p/ continuum (9.2 *vs.* 9.6). Table I shows subjects' performance for each endpoint stimulus (in proportions to allow for comparison with the results of Experiment 1). In this condition then, where subjects heard only native vowels and one endpoint on each continuum was a word,

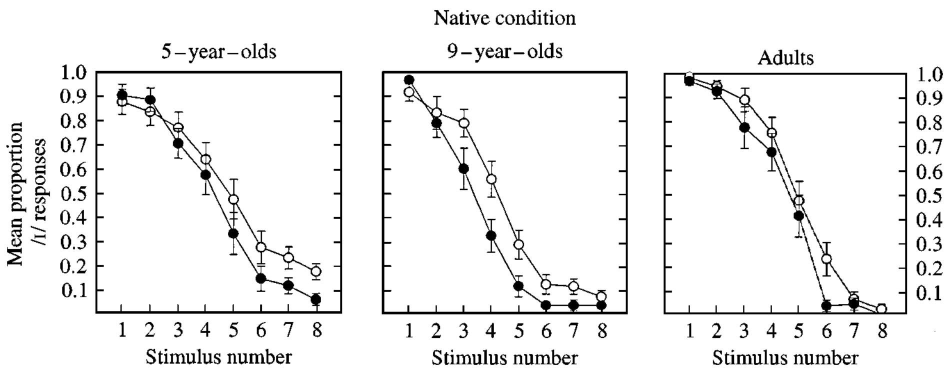

Figure 3. Mean identification functions for the two continua in the native condition for children and adults in Experiment 2. Stimulus 1 corresponds to the /ɪ/ endpoint (either /bɪb/ or */bɪp/), stimulus 8 to the /i/ endpoint (either */bib/ or /bip/). ○ /bɪb-*/bib/; ● */bɪp/-/bip/.

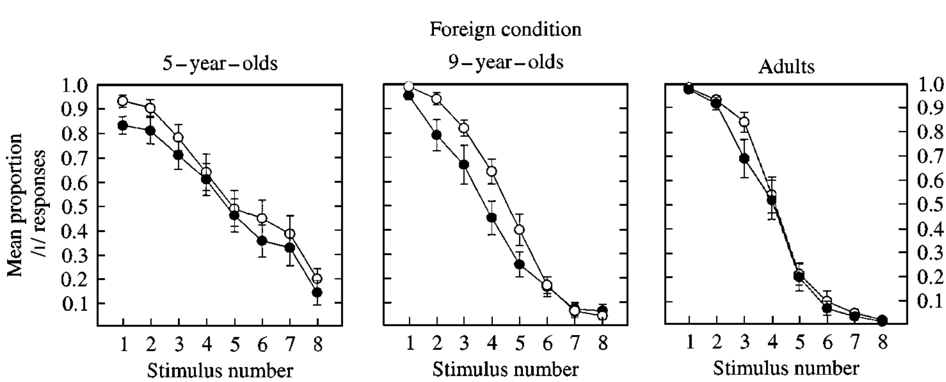

Figure 4. Mean identification functions for the two continua in the foreign condition for children and adults in Experiment 2. Stimulus 1 corresponds to the /ɪ/ endpoint (either /bɪb/ or */bɪp/), stimulus 8 to the /Y/ endpoint (either */bYb/ or */bYp/). ○ /bɪb-*/bYb/; ● */bip/-*/bYp/.

TABLE I. Mean proportion correct responses for endpoint stimuli as a function of age for the native and foreign conditions/continua in experiments 2 and 1 (standard errors are in parentheses)

Experiment 2		Native condition					
		/bɪb/-*/bib/		*M*	*/bɪp/-/bip/		*M*
5-yr-olds		0.88	0.82	0.86	0.91	0.94	0.93
		(0.05)	(0.03)	–	(0.05)	(0.03)	–
9-yr-olds		0.92	0.92	0.92	0.97	0.96	0.97
		(0.04)	(0.03)	–	(0.02)	(0.03)	–
Adults		0.99	0.97	0.98	0.97	0.99	0.98
		(0.00)	(0.02)	–	(0.02)	(0.01)	–
	M	0.93	0.90		0.95	0.96	
		Foreign condition					
		/bɪb/-*/bYb/		*M*	*/bɪp/-/bYp/		*M*
5-yr-olds		0.94	0.80	0.87	0.84	0.86	0.85
		(0.03)	(0.04)		(0.04)	(0.05)	
9-yr-olds		0.99	0.96	0.98	0.96	0.94	0.95
		(0.01)	(0.02)	–	(0.02)	(0.03)	–
Adults		0.99	0.98	0.98	0.98	0.99	0.99
		(0.00)	(0.01)		(0.02)	(0.00)	
	M	0.97	0.91		0.92	0.93	
Experiment 1		Native continuum			Foreign continuum		
		/hɪb/-/hib/		*M*	*/hɪb/-*/hYb/		*M*
5-yr-olds		0.81	0.79	0.80	0.80	0.84	0.82
		(0.03)	(0.05)	–	(0.06)	(0.04)	–
9-yr-olds		0.96	0.92	0.94	0.92	0.87	0.89
		(0.02)	(0.04)	–	(0.03)	(0.05)	–
Adults		1.00	1.00	1.00	0.92	1.00	0.96
		(0.00)	0.00)		(0.04)	0.00)	
	M	0.92	0.90		0.88	0.90	

younger children performed as well as older children, although not quite as well as adults.

For the foreign condition, an ANOVA of correct responses for endpoint stimuli (see also Table I) revealed main effects of age and endpoint [$F(2, 39) = 14.09$, $p < 0.001$; $F(2, 39) = 5.74$, $p < 0.01$], as well as significant Continuum $\times$ Endpoint, and Age $\times$ Endpoint interactions [$F(1, 39) = 6.22$, $p < 0.025$; $F(2, 39) = 3.68$, $p < 0.05$). Five-yr-olds' performance was poorer for the */bYb/ *vs.* /bɪb/ endpoint and they did not identify the */bYb/ endpoint as well as older subjects; also, their performance was poorer for the */bɪp/ *vs.* /bɪb/ endpoint, and identification of both endpoints on the /b_p/ continuum was poorer than older listeners'. However, younger subjects' performance was similar to older subjects' when the endpoint contained a native vowel and had lexical status.

3.2.3. *Phoneme boundary locations and slopes*

The top panel of Table II shows mean boundaries as a function of age and continuum for the native condition, the middle panel shows boundaries for the foreign condition, and

TABLE II. Mean boundary locations as a function of age for the native and foreign conditions/continua in Experiments 2 and 1 (standard errors are in parentheses)

Experiment 2	Native condition			
	/bɪb/-*/bib/		*/bɪp/-/bip/	
5-yr-olds	5.04	(0.33)	4.27	(0.34)
9-yr-olds	4.19	(0.31)	3.35	(0.24)
Adults	4.88	(0.23)	4.34	(0.28)
M	4.70		3.99	
	Foreign condition			
	/bɪb/-*/bYb/		*/bɪp/-/*bYp/	
5-yr-olds	5.53	(0.36)	4.78	(0.43)
9-yr-olds	4.59	(0.18)	3.80	(0.27)
Adults	4.21	(0.19)	3.94	(0.23)
M	4.78		4.17	
Experiment 1	Native continuum		Foreign continuum	
	/hɪb/-/hib/		*/hɪb/-/*hYb/	
5-yr-olds	4.33	(0.36)	5.29	(0.49)
9-yr-olds	4.24	(0.13)	4.01	(0.25)
Adults	4.51	(0.12)	4.11	(0.24)
M	4.36		4.47	

TABLE III. Mean slopes for phoneme boundaries as a function of age for the native and foreign continua/conditions in Experiments 2 and 1 (standard errors are in parentheses)

Experiment 2	Native condition				
	/bɪb/-*/bib/		*/bɪp/-/bip/		*M*
5-yr-olds	0.53	(0.06)	0.68	(0.08)	0.61
9-yr-olds	0.65	(0.08)	0.80	(0.09)	0.73
Adults	0.87	(0.09)	0.96	(0.10)	0.92
M	0.68		0.82		
	Foreign condition				
	/bɪb/-*/bYb/		*/bɪp/-*/bYp/		*M*
5-yr-olds	0.38	(0.04)	0.45	(0.08)	0.41
9-yr-olds	0.74	(0.07)	0.69	(0.11)	0.71
Adults	0.86	(0.08)	0.92	(0.09)	0.89
M	0.66		0.69		
Experiment 1	Native continuum		Foreign continuum		
	/hɪb/-/hib/		*/hɪb/-*/hYb/		*M*
5-yr-olds	0.35	(0.05)	0.38	(0.06)	0.36
9-yr-olds	0.82	(0.11)	0.68	(0.12)	0.75
Adults	1.39	(0.09)	0.96	(0.10)	1.13
M	0.85		0.67		

the lower panel shows boundaries for the native and foreign continua in Experiment 1. Table III shows the corresponding slopes.

A (3) Age × (2) Continuum ANOVA of boundary scores for the native condition revealed main effects of age [$F(2, 36) = 3.51$, $p < 0.05$] and continuum [$F(1, 36) = 26.33$,

$p < 0.001$).[8] The main effect of age obtained because across the two continua, 9-yr-olds tended to identify fewer of the stimuli as /ɪ/ than did 5-yr-olds and adults ($M = 3.77$ *vs.* 4.65 and 4.61), although none of these comparisons was significant in *post-hoc* tests. More importantly, the location of all subjects' phoneme boundary varied depending on whether or not the /ɪ/ endpoint occurred in the context of a word; specifically, the boundary extended further away from the /ɪ/ endpoint, when this endpoint constituted a word as opposed to a nonword (4.70 *vs.* 3.99). Further, the absence of a two-way interaction suggests that the size of this shift was similar across age.

An ANOVA of the corresponding slope scores revealed main effects of age and continuum [$F(2, 36) = 5.72, p < 0.01$; $F(1, 36) = 4.75, p < 0.05$]. Across the native continua, 5-yr-olds', 9-yr-olds' and adults' mean slopes were 0.61, 0.73 and 0.92; only the 5-yr-old *vs.* adult comparison was significant. Across age, slopes were steeper for the /b_p/ continuum than for the /b_b/ continuum (0.82 *vs.* 0.68).

An ANOVA of boundary scores for the foreign condition revealed main effects of age and continuum [$F(2, 34) = 5.28$; $p < 0.025$; $F(1, 34) = 14.68$, $p < 0.001$).[9] Five-yr-old's phoneme boundary (5.15) extended further away from the /ɪ/ endpoint than did 9-yr-olds' and adults' (4.20 and 4.08), regardless of the lexical status of the endpoint containing this native vowel. Across age, boundaries extended further away from the /ɪ/ endpoint, when this endpoint constituted a word as opposed to a nonword (4.78 *vs.* 4.17).

An ANOVA of the corresponding slope scores revealed only a main effect of age [$F(2, 34) = 11.34$, $p < 0.001$); 5-yr-olds' slopes (0.41) were less steep than both 9-yr-olds' and adults' (0.71 and 0.89), which did not differ from each another.

3.3. *Discussion*

The identification tasks in the present experiment were still rather difficult for young children, as evidenced by our exclusion rates: 5/19 (26%) 5-yr-olds in the native condition and 6/20 (30%) 5-yr-olds in the foreign condition did not advance to testing. (Additional subjects were excluded because their data were not suitable for analysis. However, our exclusion rates are not markedly greater than those in other similar studies; e.g., Murphy et al., 1989.) Perhaps this reflects an inherent difficulty in distinguishing the particular vowels that we examined, which are all rather close to one another in the vowel space. Indeed, in their perceptual study, Singh & Woods (1970) found that adults judge /ɪ/ and /i/ to be among the most similar of American English vowels. Also, Otomo & Stoel-Gammon (1992) observed that whereas the production of /i/ is mastered quite early (by at least 22 months of age), the production of /ɪ/ is not and substitutions of lower vowels for /ɪ/ persist even at 30 months of age. Nonetheless, those younger subjects who met our training criterion appeared somewhat better able to identify endpoint stimuli in testing than the 5-yr-olds in Experiment 1, despite having heard more stimuli. This was especially true in the native condition, where two of the four endpoints had lexical status; here, the overall proportion of correct identifications by 5-yr-olds was 0.90, *vs.* 0.86 in the foreign condition where only one endpoint was a

[8] For the /b_b/ continuum, one 5-yr-old's identification function was nonmonotonic, while another 5-yr-old's had no 50% crossover; for the /b_p/ continuum, one 5-yr-old's function had no crossover point. Thus, 3/84 (4%) missing boundary scores (and slopes) were replaced.

[9] For the /b_b/ continuum, one 5-yr-old's identification function was nonmonotonic, while another 5-yr-old's had no 50% crossover; for the /b_p/ continuum, one 5-yr-old's function was nonmonotonic, the functions of two other 5-yr-olds had no crossover. Thus, 5/84 (6%) missing boundary scores (and slopes) were replaced.

word, *vs.* 0.81 in Experiment 1 where none of the endpoints was a word. Also, in the native condition, 5-yr-olds' performance on endpoint stimuli differed only from adults', and in the foreign condition, their performance was most similar to older subjects' when the endpoint contained a native vowel and had lexical status. Further, 5-yr-olds' required only 15.4 trials to actually reach training criterion in the native condition, whereas they required 22.9 trials in the foreign condition.

Other aspects of the results indicate that vowel perception was most similar across age for the native *vs.* foreign condition. In the native condition, we observed phoneme boundary differences across continua consistent with the previous research on adult consonant perception (see Pitt & Samuel, 1993); i.e., there was a lexical effect, such that the /ɪ-i/ boundary shifted away from the endpoint with lexical status. This effect was similar across age, presumably because the word endpoints were early-acquired ones and thus highly familiar to all subjects. In the foreign condition too, boundary differences were found across continua; when a native vowel was contrasted with a foreign vowel, subjects made more responses that were consistent with the native endpoint when it had lexical status. However, for this condition, 5-yr-olds especially labeled more of the stimuli as /ɪ/ (in terms of the familiar native vowel); i.e., in comparison with older listeners, there was a shift away from the native endpoint, regardless of its lexical status, a finding also observed in Experiment 1.

The slopes of subjects' identification functions were also most similar across age in the native as opposed to the foreign condition. In the native condition, the only age difference found was that 5-yr-olds' slopes were shallower than adults', whereas in the foreign condition, 5-yr-olds' slopes were shallower than both 9-yr-olds' and adults'. The shallower slopes of our youngest subjects may be partly related to their greater difficulty with endpoint identification (again especially in the foreign condition) — a pattern also observed by Krause (1982) in her study of vowel durations as a cue to postvocalic consonant voicing with 3-yr-olds, 6-yr-olds and adults (see also Burnham et al., 1991; Kuijpers, 1996). Indeed, there was a similar progression in both the endpoint identification and slope data of 5-yr-olds across Experiments 1 and 2 as the number of word endpoints increased, such that these younger subjects' performance was more adult-like.[10]

In the native condition, it was also found that all subjects' slopes were steeper for the /b_p/ continuum than for the /b_b/ one. (A similar effect of continuum was found for the endpoint identification data.) Since this effect was not observed in the foreign condition, it cannot have been simply due to the difference across continua in the final consonant. Rather, a more viable and interesting explanation relates to neighborhood structure. In comparison with "bib" and */bib/, both */bɪp/ and "beep" have more real-word neighbors (e.g., "blip", "chip", "clip" "dip", "flip" and "cheap", "creep", "deep", "heap", etc. *vs.* "crib", "fib", "glib" and "dweeb"); i.e., there are many more words that are structurally similar to these items (words that differ by only one or two phonemes), many of which are likely to be quite well known by both children and adults. The presence in the mental lexicon of many similar words may very well prompt heightened attention to segmental information, as reflected in steeper identification slopes (for elaboration, see Fowler,

[10] Adults' slopes did appear steeper for the native continuum in Experiment 1 than for any of the continua in Experiment 2, perhaps because of the age discrepancy. However, we tested another group of young adults as in Experiment 2 and obtained similar results (Michela, Randazza, Walley & Flege, 1994). Therefore, the steeper slopes of Experiment 1 may be a spurious finding or the result of some as yet unexamined factor, such as the different initial consonant across experiments.

1991; Walley, 1993*b*). This sort of lexically-based account is also consistent with the age-related differences in performance that we observed across conditions and experiment, although clearly additional research is needed to buttress it.

Overall, the lack of marked differences in phoneme boundary location with age in this experiment is consistent with research suggesting that the vowel space is partitioned quite early in development *vis-à-vis* the native or ambient language (e.g., Kuhl, 1993; Werker & Desjardins, 1995). Still, vowel perception by children is not identical to that of adults, and our results indicate that beyond infancy, there are extant age-related differences in perception that depend on factors such as: (i) whether a native vowel is contrasted with another native vowel or a foreign one, and (ii) whether the vowel is presented in a word or nonword context. In the foreign condition, 5-yr-olds had greater difficulty than older subjects identifying endpoint stimuli, despite training (which involved more trials before meeting criterion for these young subjects) and despite receiving feedback on these stimuli in testing. In addition, 5-yr-olds' phoneme boundary always extended further away from the /ɪ/ endpoint than did 9-yr-olds' and adults' and the slopes of their identification slopes were shallower. Together, these results suggest that for younger listeners, there is still considerable uncertainty or openness as to the status of the foreign vowel. In contrast, in the native condition, 5-yr-olds performed more like older subjects with respect to training and the identification of endpoint stimuli in testing; also, the location of the /ɪ-i/ boundary did not vary with age and the slopes of 5-yr-olds' identification functions were as steep as 9-yr-olds', if not adults'. This pattern indicates that younger listeners are much more sure of the /ɪ/ *vs.* /i/ contrast.

4. General discussion

In both Experiments 1 and 2, we found that when English /ɪ/ was not bounded by another native vowel, then the category boundary extended further away from the /ɪ/ endpoint for young children than it did for older children and adults. In other words, young children tended to label more of the foreign vowel stimuli in terms of the familiar, native vowel category (a tendency that may actually have been underestimated by virtue of our exclusion criteria). Although this finding does suggest that native categories are still quite flexible in early childhood (i.e., category boundaries are not yet firmly established), it is the opposite of that predicted by the category expansion hypothesis (Flege, 1992), according to which older listeners should be most likely to perceptually equate non-native vowels with categories of the first/native language (L1). This hypothesis was motivated largely by the need to explain why individuals who learn a second language (L2) as adults tend to produce L2 vowels less accurately than those who begin to learn an L2 by the age of about 5 years. Similarly, Schouten (1975) described L1 vowel categories as exerting an increasingly strong "gravitational pull" on vowels encountered in an L2 (see also Best, McRoberts & Sithole, 1988; Kuhl, 1993).

Our finding also conflicts with the results of Butcher (1976), the only previous study of vowel perception to have afforded support for the category expansion hypothesis. In his investigation, English-, French- and German-speaking adults were more likely than children (10–12 yr of age) to exhibit perceptual clustering when judging which of two vowels in a stimulus triad were most dissimilar. Although there were numerous differences between our study and that of Butcher, the discrepancy in results is most likely attributable to stimulus and task factors. Specifically, Butcher employed only a rather small set of isolated, naturally-produced cardinal vowels (14 stimuli in total) that spanned the entire vowel space and that were intended to represent a language-general *vs.* -specific reference system. Thus, the perceptual judgments that his subjects were asked to make were much less fine-grained than those made by our subjects. However, even the stimuli that we employed did not extensively represent the three vowel categories examined, and the endpoint stimuli did not necessarily constitute best exemplars of these categories for all subjects. Therefore, it is always possible that if a wider range of stimuli and/or a different perceptual measure were employed, then positive evidence for the category definition hypothesis would be observed. For example, children might judge fewer stimuli as especially good exemplars of a given native vowel category than older listeners, or they might generalize native-language vowel category labels to a larger number of neighboring foreign vowels. Clearly, additional research is needed to fully understand the continued perceptual mapping of vowel categories in childhood.

In both experiments, we also found age-related differences in the slopes of subjects' vowel identification functions. Specifically, young children's slopes were not as steep as those of older children and adults — a result that has been observed previously in developmental studies of consonant perception (e.g., Burnham et al., 1991; Kuipers, 1996; Nittrouer, 1992). This finding for vowel perception supports the category definition hypothesis (Flege, 1992), according to which the core acoustic properties of a given phonetic category, including the weighting of these properties, become better defined with exposure to the native language (see also Nittrouer, 1996). Further, young children's slopes were steeper, and thus more adult-like, when more of the endpoint stimuli were real words. This observation is consistent with the emergent view of phoneme development (e.g., Fowler, 1991; Walley, 1993*b*), which holds that children's L1 speech representations become increasingly segmental in structure with growth in the overall size of the mental lexicon and in the number of words that must therefore be distinguished from one another (cf. Flege, Frieda, Walley & Randazza, 1998).

Are the age-related differences in phoneme boundaries and slopes that we observed truly perceptual and speech-specific, or do they reflect the operation of higher-level, post-perceptual processes of a more general nature? Although studies with adults have failed to pinpoint definitively the locus of shifts in phoneme boundaries (see Pitt & Samuel, 1993), there is evidence that their observation depends on factors such as stimulus quality. In particular, higher-level (e.g., lexical) knowledge sources may only be invoked for phoneme identification when the otherwise phonetically-rich speech signal is somehow degraded or impoverished (see Nygaard & Pisoni, 1995). The boundary differences across age that we found under conditions of relatively high uncertainty (i.e., when /ɪ/ was presented in the context of the foreign vowel) are consistent with this proposal and again would seem to indicate that native vowel categories are not yet fully specified in early childhood. What of the age differences in slopes that we found? Some time ago, Gibson (1969) observed that generalization gradients are typically less steep in childhood than in adulthood across a variety of domains (see also Bornstein, 1992). Therefore, the slope differences in the present study are probably not speech-specific, but rather an instantiation of a more general trend in perceptual development involving the increasing specificity of discrimination; in this particular domain, they may reflect differences in the adequacy of phonetic representations.

Certainly, there is still much to learn about how these representations grow and become better defined over the course of childhood. We need additional normative data regarding the perception of other vowel contrasts, the perception of vowels *vs.* consonants, and how perception is influenced by the acquisition of higher-level knowledge sources. In particular, we need more information about how phonetic identification is affected by variations in word familiarity (i.e., age-of-acquisition and experienced frequency) and neighborhood density — factors that have yet to be systematically studied in adults as well (see Pitt & Samuel, 1993). As phonetic categories become better defined, perhaps as a result of vocabulary growth, how does this impact reading acquisition and L2 learning? The increasing robustness of these categories may well provide the foundations for the emergence of explicit phoneme awareness and thus early reading skill (see Fowler, 1991; Walley, 1993*b*). Indeed, a small number of studies have found that the slopes of phonetic identification functions are especially shallow in children with reading problems (e.g., Reed, 1989; Werker & Tees, 1987). Again however, lexical influences on this aspect of perceptual performance have not been systematically assessed for these individuals, nor has the impact of intervention programs involving the presentation of modified speech input (cf. Tallal et al., 1996). In future studies examining individual differences in L2 learning, perhaps it will prove to be the case that children with relatively steep slopes (and presumably well-defined native phonetic categories) are less successful in learning to pronounce foreign sounds than those with shallower slopes (and more poorly-defined native categories). That is, successful L1 acquisition may impede L2 learning. More generally then, we need research that takes a truly developmental perspective and a more functional view of the perceptual abilities that have, to date, been most extensively documented in infancy — i.e., studies relating these abilities across different developmental periods and tasks (Haith, 1993; see also Walley, 1993*a*,*b*).

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