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Cross-language speech perception: Evidence for perceptual reorganization during the first year of life[☆]

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Abstract

Previous work in which we compared English infants, English adults, and Hindi adults on their ability to discriminate two pairs of Hindi (non-English) speech contrasts has indicated that infants discriminate speech sounds according to phonetic category without prior specific language experience (Werker, Gilbert, Humphrey, & Tees, 1981), whereas adults and children as young as age 4 (Werker & Tees, in press), may lose this ability as a function of age and or linguistic experience. The present work was designed to (a) determine the generalizability of such a decline by comparing adult English, adult Salish, and English infant subjects on their perception of a new non-English (Salish) speech contrast, and (b) delineate the time course of the developmental decline in this ability. The results of these experiments replicate our original findings by showing that infants can discriminate non-native speech contrasts without relevant experience, and that there is a decline in this ability during ontogeny. Furthermore, data from both cross-sectional and longitudinal studies shows that this decline occurs within the first year of life, and that it is a function of specific language experience. © 2002 Published by Elsevier Science Inc.

Keywords: Infants; Speech perception; Cross-language; Decline

While a large (but finite) number of sound segments occur in the languages of the world, only a subset is used phonemically (to differentiate meaning) in any particular language. Several researchers have predicted that human infants are born with the ability to discriminate the universal set of phonetic contrasts regardless of language experience, and that this ability declines as a function of specific linguistic experience (Eimas, 1978; Morse, 1978; Werker, Gilbert, Humphrey, & Tees, 1981). Alternatively, it has been proposed that experience listening to a language may be necessary to facilitate the perception of the phonetic distinctions used

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in that language (Eilers, Gavin, & Wilson, 1979). Most relevant data support the first of these predictions, suggesting that rather than having to learn to differentiate phonetic features, young infants seem to respond to speech sounds according to the categories that could serve as the basis for adult phonemic categories (for a review, see Jusczyk, 1980). Specifically, evidence shows young infants can discriminate speech sounds according to phonetic category, even if those phonetic distinctions are not used in their native language. This has been shown in the case of stop consonants differing in voice onset time (VOT) (Aslin, Pisoni, Hennessy, & Perey, 1981; Lasky, Syrdal-Lasky, & Klein, 1975; Streeter, 1976); sibilants (Trehub, 1976); vowels (Trehub, 1976), and in the case of liquids (Eilers, Oller, & Gavin, 1978). The one possible exception is the lead boundary in VOT. Although this non-English boundary has been shown to be discriminable to young English-learning infants (Aslin et al., 1981), there is evidence to suggest that it may be more difficult to discriminate without experience than other phonetic distinctions (Eilers et al., 1979).

In contrast to the evidence pointing to the infant's high level of competence, research with adults has shown that they may easily perceive only those sound differences which are used phonemically in their native language and, in many cases, may no longer be able to identify or discriminate sound distinctions used in non-native language. This has been shown to be the case in non-native speech contrasts involving differences in VOT (Lisker & Abramson, 1970; Singh & Black, 1966) and in place and manner of articulation (Goto, 1971; MacKain, Best, & Strange, 1980; Miyawaki et al., 1975; Tees & Werker, 1982; Trehub, 1976). If, as suggested, infant speech perception is characterized by a high degree of initial ability and adult speech perception is more restricted, it becomes of interest to ask how and when speech perception becomes modified (i.e., limited) to more precisely match only those sound units which are used phonemically in the learner's native language.

In our previous work (Werker et al., 1981), we compared English adults, English infants, and Hindi adults on their ability to discriminate two pairs of Hindi speech contrasts that are not used in English. One of the Hindi contrasts was the dental voiceless aspirated vs. the voiced aspirated voicing distinction /$t^h a$/-/$d^h a$/ and the other, the voiceless, unaspirated retroflex vs. dental place of articulation distinction /*ṭa*/-/*ta*/. The results showed that infants aged 6–8 months can discriminate these sounds as well as Hindi adults, but that English adults cannot, particularly in the case of the place of articulation contrast. Furthermore, English children at ages 12, 8, and 4 were as poor as the English adults in terms of their discriminative performance (Werker & Tees, 1983), showing the decline to be evident in children as young as 4 years of age. The present research was designed to examine the generality of these earlier results, and to identify the developmental time period within which the decline in non-native speech perception might occur.

1. Experiment 1

The first study attempted to determine whether the results obtained in this earlier work were representative of developmental changes in cross-language speech perception. To test this, an experiment similar to that reported by Werker and colleagues (1981) was designed using a different non-English (Thompson) place-of-articulation distinction. The Thompson language is an Interior Salish (Native Indian) language spoken in south central British Columbia.

The consonantal system of this language has two contrasting series of back stops, including plain and glottalized versions of rounded and unrounded sounds. These are variously called velars (*k*'s) and uvulars (*q*'s) or pre- and postvelar sounds (Mayes, 1979). In English, there is no distinction between back consonants, in that only velar stops carry phonemic significance. The Thompson pair chosen contrasts glottalized velar and glottalized uvular sounds, /*k̀i*/-/*q̀i*/. English infants, English adults, and Thompson adults were compared on their ability to discriminate the non-English, Thompson contrast, /*k̀i*/-/*q̀i*/.

1.1. Method

1.1.1. Subjects

Twelve full-term infants (8 girls, 4 boys) ranging in age from 6 months, 4 days, to 7 months, 29 days, with an average age of 6 months, 29 days, were recruited by advertising in local newspapers. Infants were requested to participate on days when they had no evidence of colds or ear infections. Care was taken to ensure that each infant was comfortable in the experimental room before testing began.

Ten English-speaking adults (6 males, 4 females), aged 22–35, were recruited from the University of British Columbia campus. As it is difficult to find adults with no second language training, notes were made on formal and informal training. No English adults had exposure to a second language containing the contrast being studied.

Five native Thompson-speaking adults (3 females, 2 males) ranging in age from 30 to 65 were tested on their discrimination of the Thompson tokens.

1.1.2. Stimuli

Multiple natural exemplars of each sound were used in the discrimination task, so that subjects would have to ignore within category acoustic variability and differentiate the sounds according to phonetic category, much as is done in natural language processing. Care was taken to ensure that the exemplars from the two categories were equated for intensity, fundamental frequency, duration, and intonation contour. The English contrast used was the place of articulation distinction, /*ba*/-/*da*/, in which bilabial and alveolar voiced stop consonants are differentiated. Four exemplars of /*ba*/ and four exemplars of /*da*/ were used. The Thompson (non-English) contrast /*k̀i*/*q̀i*/ involved two glottalized voiceless stop consonants where the uvular vs. velar place of articulation distinction is the critical difference. These sounds are produced by obstructing the air flow by raising the back of the tongue either against the velum (velar) or behind the velum (uvular). Back consonants are characteristic of North American Indian languages. English listeners typically label both velar and uvular stops as velar, since uvular consonants are not typically used in English.

In recording native Indians who are not accustomed to reading their language, it was necessary to record whole words, and then ask the speaker to repeat the first consonant–vowel (CV) sound. It was then possible to perform acoustic analyses of words and CV repetitions to ensure that the CV syllables contained the same consonant sounds as the words. The vowels in Interior Salish languages vary (somewhat in free variation and in a somewhat systematic fashion) between speakers and between consonants (Thompson & Kinkade, in press). In over 100 recordings of *k* and *q* words and sounds from three different speakers, we were unable to find exemplars wherein a similar enough vowel followed multiple CV only repetitions of *k* and *q*.

In the CV repetitions from the words *k̀ixm* (to fry an egg) and *q̀ixm* (to make one see), however, there was one exemplar (or token) of /*k̀i*/ and one token of /*q̀i*/ in one speaker's recording in which the vowels sounded nearly identical to one another and appeared similar in a wave form analysis. Since there is a discontinuity in the wave form of glottalized stops(a 0 amplitude segment in the wave form) it was easy to use the /*i*/ periodic segment from a single /*k̀i*/ and the /*i*/ periodic portion from a single /*q̀i*/ to splice on to additional exemplars of the ejective portion taken from other *k* and of *q* repetitions. This was done to yield three tokens of /*k̀i*/ with a single /*i*/ segment and three different ejective portions, and three tokens of /*q̀i*/ with a single /*i*/ segment and three different ejective portions.

Classical spectrographic analysis has been shown to provide little information as to the acoustic differences between velar and uvular sounds (Mayes, 1979). In our spectrographic analysis, the only apparent differences between typical spectograms from /*k̀i*/ and /*q̀i*/ were in the third formant transition, and possibly in the amplitude and duration of the burst. F_3 is flat for /*q̀i*/ at around 2300 kHz, whereas it rises for /*k̀i*/ from 2400 kHz to approximately 2900 kHz. The amplitude and duration of the /*q*/ burst are greater than in the /*k*/ burst. Representative spectograms are shown in Fig. 1. The average duration for each token was 400 ms with a 1500 ms silent interval between tokens. Final tapes were prepared and set-up with the use of the PDP-224 computer at Haskins Laboratories in New Haven, CN. All tapes were played on a Revox A-77 tape recorder at approximately 65 db SPL in a tracoustics sound-attenuated test chamber. The entire operation was controlled by a logic system (Werker et al., 1981).

1.1.3. Procedure

Infants were tested in a "head turn" (HT) paradigm (sometimes referred to as "visually reinforced infant speech discrimination" paradigm) in which the infants were conditioned to turn their heads away from an experimental assistant and toward a loud speaker within a specified time interval (4.5 s) when there is a change in the speech sound category. Correct head-turns are reinforced with the presentation, and illumination, of an electrically activated toy animal inside a smoked plexiglass box while incorrect head-turns (i.e., false positives) are not reinforced. Three exemplars of /*k̀i*/ were set-up in random order on Track 1 of a two-track tape, and 3 exemplars of /*q̀i*/ were set-up and aligned on Track 2. When changes from Track 1 to 2 occurred during the testing, the subject's task was to indicate when there was a change in the phonetic category from /*k̀i*/ to /*q̀i*/. in this sense, it could be argued that the HT procedure functioned as a categorizing discrimination task since multiple exemplars were used. However, exemplars from a single category were much more similar than those typically used in categorizing tasks (cf. Kuhl, 1979).

In the experimental set-up the infant sat on its parents' lap facing an experimental assistant (E2) across the table in a sound-attenuated chamber. The speaker and the visual reinforcer were located at a 110°, 90 cm to the left of the parent/infant. Both the parent and E2 wore headphones through which music was played so they would not be able to influence the infant's behavior. The E2 kept the infant looking in his/her direction by manipulating small toys.

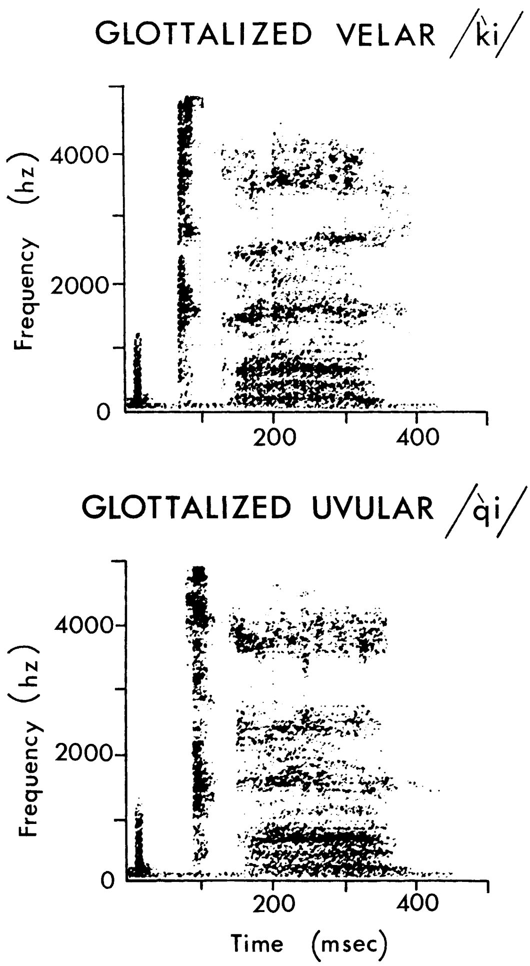

Fig. 1. Spectograms of typical exemplars of the Thompson glottalized velar/uvular contrast (/*k̀i*/-/*q̀i*/).

Another Experimenter (E1) sat outside the chamber observing the infant through a one-way observation window and monitored the logic system console (for details, see Werker et al., 1981).

In the conditioning phase of this procedure, the experimenter activated the toy animal immediately following a sound change. Once the infant formed the association between the sound change and activation of the toy animal (usually within 2–10 trials), the infant, upon hearing the sound change, turned its head to see the toy animal perform, and activation of the reinforcer became contingent on an appropriate head turn.

When conditioning was successful (i.e., three correct anticipatory head turns in a row) presentation of stimuli and activation of the visual reinforcer became controlled by a logic system. Every time the infant turned its head, E2 pressed a button on the floor. All button presses were recorded on a Grason–Stadler event recorder. If the button press occurred within 4.5 s of the stimuli changing from one phoneme (i.e., *ba*) to another (i.e., *da*), the visual reinforcer was activated by the logic system. A record of each was recorded. The operation of the logic system also yielded a record of each time an infant did not turn his/her head during a change trial (i.e., misses) and each incorrect head turn (i.e., false positives).

A variate of this paradigm was used with adult English subjects where a button press rather than a head-turn was the required behavioral response (see Werker & Tees, 1983).

The criterion for successful discrimination was 8 out of 10 correct responses to *change* trials with no more than two errors (i.e., two misses or two false positives).[1] The criterion for deciding an infant could not discriminate a contrast had two phases. First, the infant had to successfully discriminate /*ba*/-/*da*/ directly before and after failing to reach criterion on a non-native contrast. This was done to ensure that the failure of the infant was due to an inability to readily perceive the sound difference, and was not due to non-specific factors such as boredom, dirty diapers, etc. Two infants (1 male, 1 female) were eliminated from further analysis because they failed this phase. Second, the infant was given 25 change trials on the non-native contrast in their unsuccessful attempt to reach criterion. Adults were also given 25 change trials in which to reach criterion.

1.2. Results and discussion

The portion of subjects that either reached or did not reach the 8 out of 10 criterion on the Thompson contrast is illustrated in Fig. 2. All 5 of the adult Thompson speakers reached criterion, whereas only 3 out of 10 adult English speakers did so. Of the English infants tested, 8 out of 10 reached criterion.

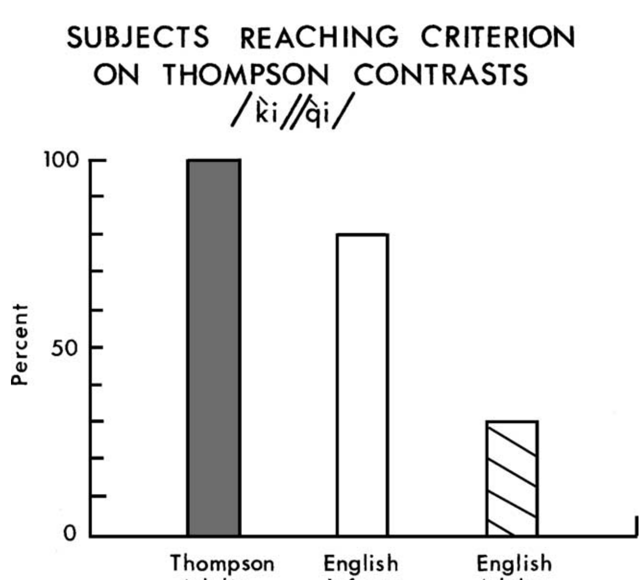

Fig. 2. Proportion of Thompson-speaking adults, English-speaking adults, and infants from English-speaking homes reaching criterion on the Thompson glottalized velar/uvular contrast (/*k̀i*/-/*q̀i*/).

An analysis of proportions based on a Chi-square analogue of the Scheffe theorem (Marascuilo, 1966) was applied to these data. This yielded a significant overall Chi-square $p < .05$; $\chi^2 = 8.94$). Multiple comparisons between the different groups were performed to determine which groups differed. The results showed that performance of the Adult English speaker was significantly worse than performance of either the Adult Thompson or the Infant English groups. The difference between the English infants and the Thompson adults was not significant.

These results were similar to those obtained in our earlier work (Werker et al., 1981). They showed that a decline in cross-language speech perception is evident between infancy and adulthood. That is, young infants discriminate the place of articulation contrasts according to linguistic category without specific linguistic experience, whereas adult speech perceptual ability is more limited, reflecting discrimination of only those contrasts which are phonemic in the listener's native language.

2. Experiment 2

The second experiment was designed to establish the developmental time period in which the decline in speech discriminative ability occurred. In this endeavor, subjects were tested on both the Thompson /*k̀i*/-/*q̀i*/ contrast, as well as on one of the Hindi contrasts (/*ṭa*/-/*ta*/) employed in our earlier research (Werker et al., 1981). Two contrasts were used to increase our confidence in the generality of any results we might obtain.

Since we had already ascertained that by age 4, children appear to discriminate non-native contrasts as poorly as adults (Werker & Tees, 1983), we decided to examine perception in children between the ages of 8 months and 4 years. After testing about 15 children of various ages, it became apparent that important changes were occurring during the first year of life. At that time, we narrowed our investigation to study cross-language perception in infants between 6 and 12 months of age. In addition to testing English infants, there was an attempt to test infants being raised in homes in which either Hindi or Thompson was primarily spoken. This was done to determine whether the observed decline was a result of specific language experience, or whether it could be explained by a general developmental decline in the ability to make difficult perceptual distinctions.

2.1. Method

2.1.1. Subjects

In this study, data were collected from infants aged 8–10 months and 10–12 months, and were compared to the earlier data we had collected on infants aged 6–8-month-old under identical testing conditions, either in a previous study (Werker et al., 1981) in the case of the Hindi contrast or from Experiment 1 of the present study in the case of the Thompson contrast. One group of 8–10-month-old children (7 females and 5 males, ranging in age from 8 months, 3 days, to 9 months, 10 days, with an average age of 8 months, 20 days) was tested on the Hindi contrast. A second group of 9 females and 5 males (ranging in age from 8 months to 9 months, 12 days with an average age of 8 months, 18 days) was tested on the Salish contrast. (An additional

3 infants were dropped from further analysis for failing to reach for failing to reach criterion on /*ba*/-/*da*/.) One 10–12 month-old group (5 females and 5 males, ranging in age from 10 months, 2 days, to 11 months, 15 days, with an average age of 10 months, 20 days) was tested on the Hindi contrast. A second group of 5 males and 5 females (ranging in age from 10 months, 2 days to 12 months, 4 days, with an average of 10 months, 29 days) was tested on the Salish contrast. (Data from 12 infants aged 10–12 months had to be discarded because they failed to reach criterion on the /*ba*/-/*da*/ contrast). All subjects were recruited from advertisements in the local newspapers.

2.1.2. Stimuli and procedures

All infants were tested on the English labial/alveolar contrast /*ba*/-/*da*/. The two non-English contrast used were the Thompson glottalized velar/uvular contrast /*k̀i*/-/*q̀i*/ (as described in Experiment 1) and the Hindi unvoiced unaspirated retroflex/dental contrast /*ṭa*/-/*ta*/. The Hindi language distinguishes four places of articulation in contrast to the three used in English. Dental stops are produced by obtsructing the air flow by placing the tongue back, and placing the top posterior to the alveolar ridge. The retroflex and dental Hindi stop consonants would both be typically categorized as alveolar, [*t*] by an English listener.

Four exemplars of each sound were recorded by a native speaker. Final exemplars were chosen so that variations in duration, fundamental frequency and intonation contour were randomized both within and between phonetic categories. The average 500 ms, with a 1500 ms interstimulus interval.

Acoustic analyses showed the main cues differentiating these naturally produced speech sounds to be in amplitude of the burst, and in the slope of the second and third formant (Fig. 3); for a full description of those stimuli, see Werker et al. (1981). Infants were tested in the HT procedure as described in Experiment 1. Requirements for concluding an infant could not reach criterion on a contrast were identical to those of Experiment 1.

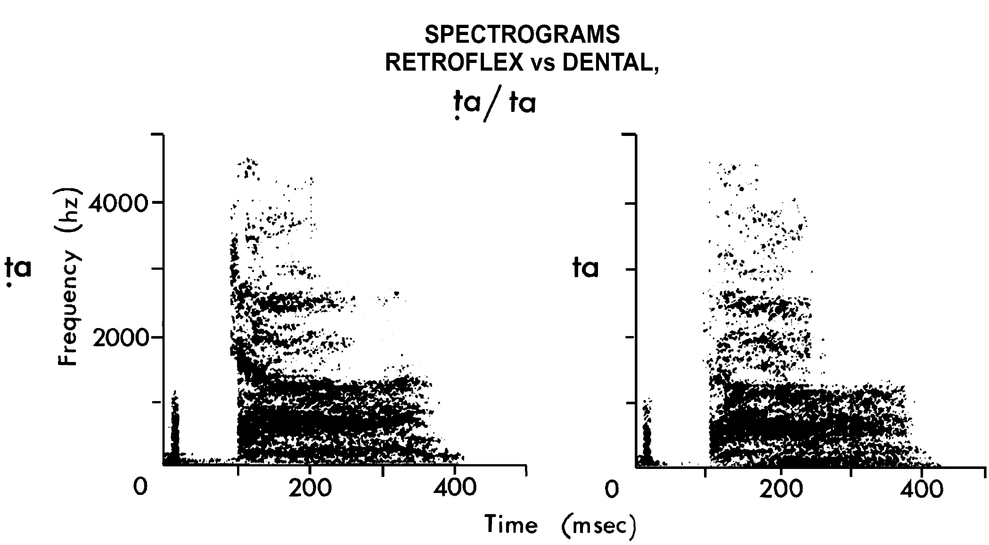

Fig. 3. Spectrograms of typical exemplars of the Hindi retroflex/dental contrast, /*ṭa*/-/*ta*/.

Table 1
Infant discrimination performance on two non-English speech contrasts

Reached criterion	6–8 months	8–10 months	10–12 months
	The retroflex/dental contrast /*ṭa*/-/*ta*/		
Yes	11	8	2
No	1	4	8
	The velar/uvular contrast /*k̀i*/-/*q̀i*/		
Yes	8	8	1
No	2	6	9

2.2. Results and discussion

The number of subjects that either reached or did not reach criterion on the two contrasts is shown in Table 1. As can be seen, most of the infants aged 6–8 months reached criterion on both contrasts, whereas by 10–12 months of age, few infants reached criterion, whereas by 10–12 months of age, few infants reached criterion on contrasts. The overall χ^2 was significant $p < .05$) for both contrasts ($\chi^2 = 21.67$ for /*k̀i*/-/*q̀i*/; $\chi^2 = 24.59$ for /*ṭa*/-/*ta*/). Planned multiple comparisons showed the significant differences to be between the 6–8-month and the 10–12-month groups ($p < .001$), and between the 8–10- and the 10–12-month groups $p < .05$). This suggests that the 10–12-month-old performed significantly less well than the two groups of younger infants on both contrasts.

The number of trials to criterion was compared across contrasts and across ages for those infants who could discriminate the sounds. It was assumed that if the decline in the ability to discriminate non-native contrasts according to phonetic category occurred gradually between 6 and 12 months of age, this gradual change would be evident in an increase in the number of trials required to reach criterion. However, a 3×3 repeated measures analysis of variance showed there to be no significant differences between age groups, $F = 1.57$, $p < .05$, or between sound contrasts $F = 2.78$, $p < .05$, making it difficult to argue that there was a gradual increase across age in the number of trials required to reach criterion.

To make sure that the decline around 10–12 months of age was not simply a function of a general performance decline for difficult perceptual tasks at this age, a few same-aged babies being raised in homes in which Hindi or Thompson are primarily spoken were also tested. To date, we have only been able to find 5 infants (3 Hindi and 2 Thompson) between 11 and 12 months who meet this criterion, and only 3 of these infants who would condition in the HT procedure (i.e., reach criterion on the *ba*/*da* contrast). This drop-out rate is similar to that found in the same-aged English infants. All three of these infants reached discrimination criterion on their native contrast within 10 change trials.

These findings show the decline in the ability to discriminate non-native phonetic contrasts occurs within the first year of life. That is, most of the English infants tested could discriminate both non-English contrasts at 6–8 months of age. By 8–10 months a smaller percentage could discriminate the contrasts, and by 10–12 months the infants were performing as poorly as the young children and adults in Experiments 1 and 2. However, infants being raised to speak Hindi or Thompson sounds could still discriminate the relevant contrasts at 11–12 months of age. The results provide strong support for the supposition that specific linguistic experience is necessary to maintain phonetic discrimination ability. Without such experience, there is a loss in this ability by 10–12 months of age.

3. Experiment 3

The two-part criterion employed in Experiment 2 (i.e., reaching criterion within 25 change trials and passing /*ba*/-/*da*/ before and after failing a non-English contrast) for concluding that an infant could or could not discriminate a non-native contrast resulted in an unequal drop-out rate which may have biased the results obtained for infants in the 10–12-month range. (Completion rate was only 60% in the 10–12-month group compared to 85% in the 6–8- and 8–10-month group. Older infants prefer to try to "visit" the toy animal, rather than simply turn their head to see it). To control for this possible confound and to examine within subject developmental change, we decided to attempt to replicate Experiment 2 using a longitudinal design.

3.1. Subjects

Six subjects, 3 males and 3 females, were tested successively at three ages. Subjects were chosen who were particularly cooperative in the procedure at 6–8 months of age, in the hope that these same subjects would be relatively more cooperative at 10–12 months of age. During Time 1 (6–8 months), infants ranged in age from 6 months, 22 days, to 7 months, 29 days, with an average age of 7 months, 15 days. At Time 2 (8–10 months), the infants ranged in age from 8 months, 22 days, to 9 months, 25 days, with an average of 9 months, 2 days. At Time 3 (10–12 months), the infants ranged in age from 10 months, 2 days to 11 months, 11 days, with an average of 10 months, 22 days.

3.2. Stimuli and procedure

Infants were tested on the Hindi contrast /*ṭa*/-/*ta*/, the Salish contrast /*k̀i*/-/*q̀i*/, and the English contrast /*ba*/-/*da*/. In addition, the HT procedure was used.

3.3. Results and discussion

The results from this longitudinal study replicate those from the cross-sectional study. In this experiment, all 6 subjects reached criterion on both non-English contrasts when they were 6–8 months of age. When the subjects reached 8–10 months, all 6 reached criterion on the Hindi contrast, and only 3 reached criterion on the Thompson contrast. By 10–12 months of age, none of the 6 infants reached criterion on either contrast even though they could reach it on the English /*ba*/-/*da*/ both before and after failing the Thompson sound.

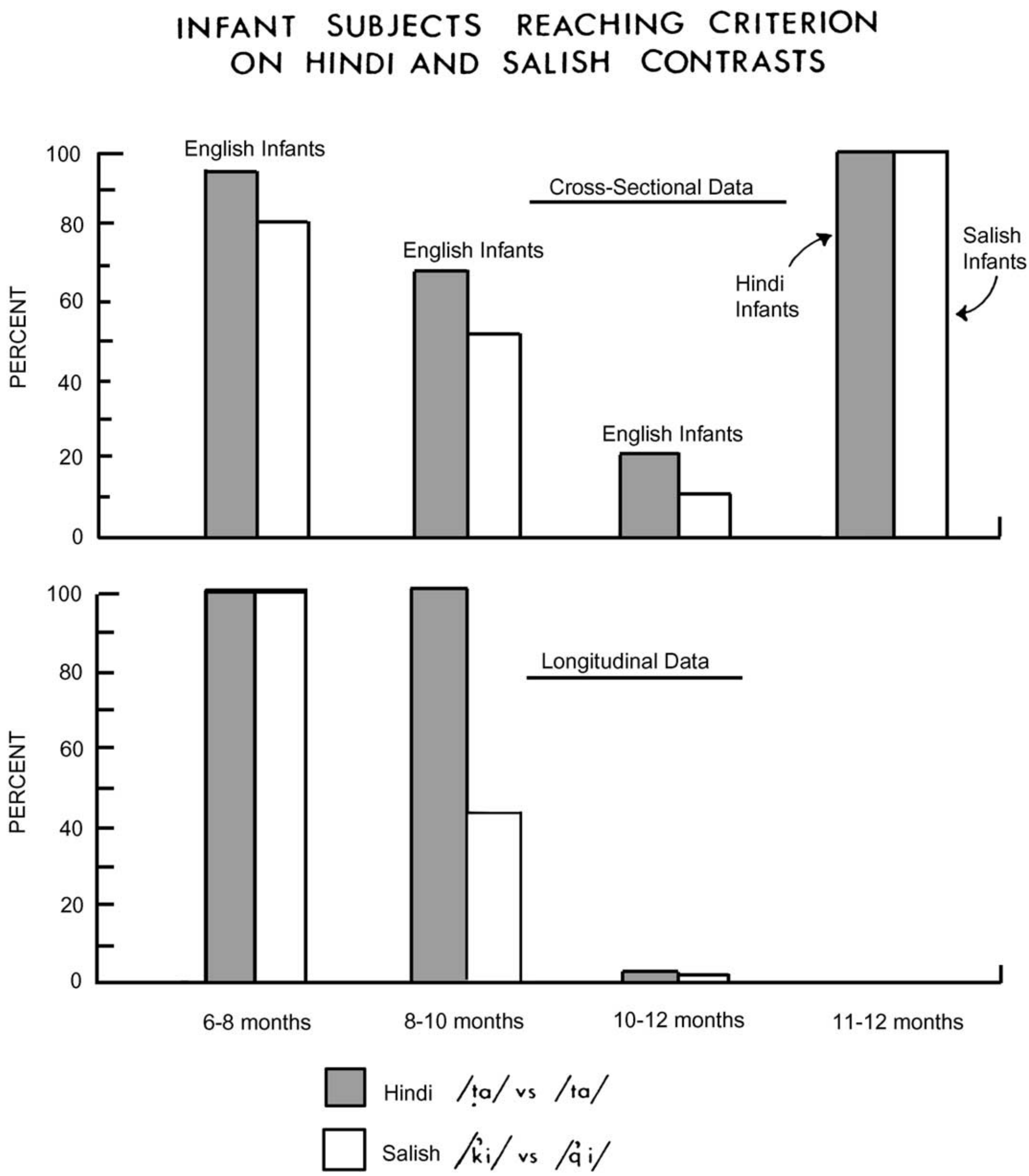

Fig. 4. Proportion of infant subjects from three ages and various backgrounds reaching criterion on Hindi and Thompson (Salish) contrasts.

In examining the data, it can be seen that the results from the longitudinal study closely match those from the cross-sectional study (see Fig. 4). The pattern of change across infancy is precisely mirrored for the Thompson contrast. The time course of the change was somewhat different in the case of the Hindi contrast, with an apparent abrupt decline in discriminability occurring when subjects reached 10–12 months of age.

4. General discussion

In summary, these experiments provide strong support for the claim that young infants can discriminate many of the phonetic distinctions used across natural languages without relevant experience, and that there is a decline in this ability as a function of specific language experience. Furthermore, these experiments provide data showing that this decline may be evident by the end of the first year of life.

It is easy to understand how an innate ability to perceive speech sounds according to phonetic categories would ease the process of language learning, and the eventual identification of meaningful units by predisposing the infant to segment sounds according to functionally useful categories. In addition, highly refined infant discriminative abilities followed by a selective loss (and/or broadening) of category boundaries could facilitate the learning of particular languages and dialects by allowing for the selective tuning of initial sensitivities in accordance with a specific phonology. It is probably no accident that this decline, or tuning, occurs at about the age that the child is beginning to understand and possibly produce sounds appropriate to his/her native language. It could be expected that this perceptual reorganization is closely related to the acquisition of phonological contrasts. In future work we are interested in investigating the relationship between cross-language speech perception performance and both vocal output and language comprehension. Finally, we are interested in ascertaining whether the changes identified in both speech perception and production performance are mediated by general changes in cognitive functioning, or whether they are more a function of specific perceptual learning.

Note

1. Typically, in the HT procedure, head-turns are only counted during demarcated observation intervals (e.g., Aslin et al., 1981; Kuhl, 1979; Werker et al., 1981). In this series of experiments, we modified the procedure and controlled for bias by random manipulation of the timing between experimental trials. To do this, we had to bring each infant under tight experimental control during conditioning. For example, if an infant was inclined to make frequent false positive head-turns, we extinguished that response proclivity by lengthening the interval between sound changes. Following conditioning, experimental trials occurred according to a random schedule (every 4–15 trials) when the infant was continuously oriented toward the experimental assistant. Since the timing of experimental trials varied, control trials were not used. Every head-turn during this period was counted, yielding an overall probability of $<.01$ for achieving an 8 out of 10 correct response to change trials.

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