The acquisition of voicing contrasts in Spanish and English learning infants and children: a longitudinal study*

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(Received 21 December 1982)

ABSTRACT
The production of voice-onset time (VOT) was studied in a group of Spanish- and English-learning subjects at 1 and 2 years of age. Voice-onset time of initial stop consonants from canonical utterances was measured oscillographically. At one year no significant difference in VOT production was found between Spanish and English learners at any place of articulation. Mean VOT values for infants fell in the short lag range. By two years, four of the seven children in the English group and four of the children in the Spanish group showed significant evidence of having acquired the VOT distinction in stop consonants appropriate for their native language.

INTRODUCTION
The study of speech sound acquisition has in recent years begun to focus on the differences between phonological abilities of children learning different languages. The acquisition of voicing or voice-onset time (VOT) contrasts for stop consonants has held particular interest because (1) a wide variety of languages employ voice-onset time to distinguish homorganic stop consonants (Lisker & Abramson 1964, 1970), (2) languages partition the VOT continuum differently yielding varied voicing contrasts among homorganic stops (Abramson & Lisker 1970, Williams 1977), (3) infants are able to perceive some characteristics of voicing in stop consonants from soon after birth (Eimas, Siqueland, Jusczyk & Vigorito 1971, Eilers, Morse, Gavin & Oller

[*] This research was supported by NIMH grant no. 30634 to the senior author and by the Mailman Foundation. We wish to thank all of the parents who participated in this longitudinal study for their support, patience, persistence and encouragement and Dr Dale Bull for his assistance with data analysis. Address of first author, for correspondence: Department of Pediatrics, Mailman Center for Child Development, P.O. Box 016820, Miami, Florida 33101.
In the only available instrumental cross-linguistic study of voicing production in infants, Preston, Yeni-Komshian & Stark (1967), studying English-learning and Lebanese Arabic-learning infants, found evidence that by the end of the first year of life normal infants do not show voicing distinctions in their babbling. Comparing data collected from the two groups of infants, the authors found that apical (dental) stop VOT values fell predominantly in the short lag region (between 0 and 30 msec) for both groups of infants. By three years of age, children in both these communities showed appropriate voicing distinctions. The results on infants of the Preston et al. study conform to results of transcriptional analyses reporting that English-learning infants (Oiler, Wieman, Doyle & Ross 1975) and Spanish-learning infants (Oller & Eilers 1982) tend to produce primarily short lag stops.

In a study of acquisition of voicing contrasts in meaningful speech, Clumeck et al. (1980) investigated the production of Cantonese stops at three places of articulation. Children aged 2;6 to 4;0 showed evidence of having acquired the Cantonese short lag/long lag voicing contrast. Similarly Macken & Barton (1980a) and Gilbert (1977) report acquisition of the short lag/long lag distinction by English-learners between two and four years of age. All the reports emphasize that long lag stops were more variable in VOT than short lag stops at the time that the contrast was acquired.

In contrast to previous findings about English, Cantonese and Arabic (Gilbert 1977, Preston et al. 1967, Zlatin & Koeningsknecht 1976, and Macken & Barton 1980a), Macken & Barton (1980b) found that Mexican Spanish-learning children showed little evidence of a phonetic lead versus short lag voicing contrast as late as four years of age. This finding was particularly surprising given that Spanish-learning infants (at 0;6-0;8) show the ability to discriminate lead vs short lag stop consonants significantly better than their English-learning peers (Eilers et al. 1979). Since the Spanish learners appear to use specific linguistic experience at an early age to master perceptually the less salient lead vs short lag contrast (Eilers et al. 1981), it is surprising that the Spanish learners in the Macken & Barton study were at least two years behind their English-learning counterparts in their ability to produce appropriate stop consonant voicing contrasts.

Macken & Barton's (1980b) results leave us with the question of why voicing contrasts in stop consonants appear to be acquired later in one linguistic group (Spanish) than others (Cantonese, English). Three explanations might account for this discrepancy. First, Spanish-like stop consonants may be discriminated later than English stops, and thus may be acquired later. This possibility is minimized by data on discrimination of Spanish stops by
Spanish-learning infants (Eilers et al. 1979). The second possibility is that the Spanish lead stops are more difficult to articulate than long lag stops. Tentative support for this hypothesis is supplied by Macken & Barton (1980b) who found that children showed a productive awareness of some voicing contrasts in Spanish by spirantizing initial-position stops if the adult form was voiced (i.e. lead). However, these children were four years old, one to two years older than the children who have been shown to have acquired the English voicing contrast. Finally, special characteristics of Spanish phonology or of the particular Spanish dialect studied by Macken & Barton (1980) might predispose learners to avoid production of lead stops until relatively late. Learners of other dialects of Spanish or other languages with lead stops might not show the same avoidance.

The acquisition of the ability to produce voicing contrasts is, thus, only understood in broad outlines and many mysteries remain. Further cross-linguistic research is needed to help elucidate the various influences on the process of acquisition. The present paper reports two cross-linguistic experiments on the development of the voicing contrast in Cuban Spanish and American English. The purposes of these studies are twofold: to provide developmental data on the acquisition of voicing contrasts by children in both pre-meaningful and meaningful stages of development and to provide a data base for Spanish learners to compare with Macken & Barton (1980b). For this last purpose, Cuban Spanish is a fortunate choice since it differs in important phonetic details from Mexican Spanish. English was chosen to contrast with Spanish since a large data base already exists for two-year-old English learners, a base that can be used for comparison purposes with the present study. The English data offer a methodological anchor against which the Spanish data can be compared within the same study. Fourteen children have been followed longitudinally from infancy and data are reported from two points in their development: near the end of the first year and later during the beginning of the third year.

EXPERIMENT I

METHOD

Subjects

Seven English (4 females, 3 males) and seven Spanish-learning infants (4 females, 3 males) were selected from the Greater Miami area. All infants had normal pre- and peri-natal histories and normal onset of developmental milestones. All were in good health and had no history of hearing loss. Six of the Spanish-learners came from predominantly Cuban Spanish-speaking homes and one from a Colombian Spanish-speaking home, while all of the English learners came from monolingual American English homes.

High-fidelity tape recordings were made over a number of sessions when
the children were between 0;8 and 1;2 (mean age for the English learners was 0;11.4, for Spanish learners 0;11.0). The mean number of recording sessions for the Spanish group was 5 (range 2–8) and for the English group 6 (range 4–7).

Procedure
Infants were recorded using a high-fidelity tape system in a sound-attenuated booth while interacting with the experimenter and the parent. On-line comments were added to the tape by the experimenter documenting place of articulation whenever visible. Recording sessions averaged 20 minutes. If infants did not produce canonical utterances (utterances composed of adult-like consonants and vowels) with initial stop consonants, or if an insufficient number of utterances was obtained, infants were re-recorded a few days later. An average of 34 appropriate canonical utterances were collected per infant across the two groups. All of the tapes were coded by two trained transcribers using a version of the International Phonetic Alphabet modified to include representations of special features of infant vocalizations. All clear-utterance initial-stop consonants where transcribers agreed on place of articulation were instrumentally analysed for timing of voice onset. All utterances were measured on a Tektronix storage oscilloscope using a manual trigger. The manual trigger assured that the onset of utterances could be accurately determined. Measurement of VOT with absolute values of less than 50 msec was accomplished with an inter-observer disagreement not exceeding 2 msec. Larger VOT's were susceptible to greater error (though not exceeding 20 msec values or for VOT greater than 200 msec) because longer utterances necessitated time compression for display on the oscilloscope screen.

RESULTS
Results of the analysis of infant stop consonants are presented in Figs. 1 a (for Spanish) and 1 b (for English). Each bar in the histograms represents the proportion of all stops at a given place of articulation that had the specified VOT value. Spanish-learning infants produced 54% of all utterance-initial labial stops in the short lag range (VOT 0–30 msec), 6% in the long lag range (VOT 31 msec or greater) and 40% with voicing lead ( — 1 msec or less). Similarly, for English-learning infants, 51% of labial stops were produced within the short lag range, 16% with long lags and 33% with voicing lead.

Utterance-initial dental stops were produced with short lag by Spanish-learning infants 77% of the time. Ten per cent were produced in the long lag range and 13% had voicing lead. English-learning infants had almost identical values; short lags accounted for 72% of dental stops, while only 12% were long lag and 16% had voicing lead.

Spanish-learning infants produced 66% of velar stops in the short lag
Fig. 1a. Distribution of VOT values for Spanish-learning infants at three places of articulation.

Fig. 1b. Distribution of VOT values for English-learning infants at three places of articulation.
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range, 30% with long lags and 4% with voicing lead. English-learning infants had comparable values of 56% short lag, 23% long lag and 21% voicing lead for velar stops.

A two-way mixed analysis of variance with one between-factor (Language Experience: Spanish or English) and one within-factor (Place of Articulation: Labial, Dental, Velar) was computed for all infant utterances. No significant difference was found between Spanish- and English-learning infants. A significant main effect was found for Place of Articulation. Mean VOT for labials, dentals and velars respectively was $-10.04$ msec, $4.39$ msec and $12.97$ msec ($F = 3.35; 2, 24$ d.f.; $P < 0.05$). Post hoc comparisons revealed that the means for labials and velars differed significantly from one another ($t = 3.62, P < 0.05$). No other difference was significant.

DISCUSSION

The results of Preston et al. (1967) showed that English and Lebanese Arabic-learning infants at the end of the first year had not acquired native voicing contrasts. In fact, the two groups showed nearly identical distributions of VOT for apical stops. The range of reported VOT values for both language groups was 0–30 msec. The present data support the Preston et al. (1967) result in that no significant difference was found between language groups. The distributions of VOT values collected from the English and Spanish learners was, however, wider (−185 to 165 msec VOT) in the present study than that reported by Preston et al. (1967). However, the modal value for dentals for infants in both studies was in the short lag range. The results of the present study also conform with those of transcriptionally based studies that have reported a predominance of short lag stop consonants in babbling of English-and Spanish-learning infants (Oller et al. 1975, Oller & Eilers 1982).

Significant differences were found across language groups in the present study for place of articulation. Labials tended to have more voicing lead while dentals had almost simultaneous voicing and release of stop closure and velars had short voicing lag. This pattern is reminiscent of that found for English-speaking adults (Lisker & Abramson 1970), who show larger VOT values as place of articulation is shifted toward the back of the mouth.

In summary, these results suggest that by the end of the first year of life, infants whose languages contain different phonemic category boundaries for initial stop consonant voicing do not reflect these differences in any obvious systematic production distinctions. In order to study the development of the differentiation of voicing categories, Experiment II was undertaken.
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Experiment II

Method

Subjects

All seven English-learning infants from Experiment I returned at 2;3–2;6 (mean age 2;2.5) to participate in Experiment II. At that time children were progressing normally and were all producing age-appropriate meaningful speech. Five of the seven original Spanish-learning infants returned for Experiment II between the ages of 2;1 and 2;5 (mean age 2;2.6). Two additional Spanish-learning two-year-olds were recruited for Experiment II, bringing the mean age to 2;3.5. The Spanish group for Experiment II included four females and three males.

Procedure

A tape recording of each of the 2-year-olds was made in a sound-attenuated booth with high-fidelity recording equipment. Both the parent and bilingual experimenter were present. All instructions were given to the child in his/her native language. The child was presented with one of nine model utterances ([ba], [pa], [pʰa], [da], [ta], [tʰa], [ga], [ka] or [kʰa]). The pre-voiced and short lag stops were native for the Spanish learners, while the short lag and long lag stops were native for the English learners. Children were reinforced with edibles for attempting to imitate the models. No correction for voicing control was offered by the experimenter. In a few cases where place of articulation was imitated incorrectly, correction was attempted unsuccessfully. These instances are noted in the results.

The experimenter elicited five tokens of each stop type. In each case the model was presented to the child before each imitation. With the exception that five tokens of each stop type were collected consecutively, voicing models were randomly presented. After the 45 imitations were collected (five of each stop type at each place of articulation) the experimenter attempted to obtain a second set of 45, either in the same session or at a subsequently scheduled session. In 11 of 14 cases the data base was expanded to 90 utterances per child. Three Spanish-learners were either not available or uncooperative in providing the second set of 45.

All utterances were judged for place of articulation by two listeners and VOT was measured using the same procedures as in Experiment I. Oscillographic measurements were made of the experimenter models to ensure that the child received the correct model. The mean model VOT for lead stops was $-177.15$ msec (s.d. = 49.96), for short lags 2.82 msec (s.d. = 4.63), and for long lags 118.47 msec (s.d. = 24.25). An adult bilingual listener judged all models to be easily within the appropriate adult categories for voicing in Spanish and English. The VOT values for both the lead and long lag stops were exaggerated by adult standards to emphasize the relevant distinctions.
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(2A)

Long lag model

Short lag model

Lead model

(2B)

Long lag model

Short lag model

Lead model

For caption see p. 322.
Fig. 2. Distribution of VOT values for imitated syllables for Spanish-learners at the labial (A), dental (B) and velar (C) places of articulation.
Fig. 3. Distribution of VOT values for imitated syllables for English-learners at the labial (A), dental (B) and velar (C) places of articulation.
short lag labials with short lag productions. In contrast only 7% of long lag stops were produced with appropriate long lags; instead the majority were imitated as short lags. The general pattern held true for the dentals as well. The picture for velar stops is somewhat different in that velars had less tendency to be produced with voicing lead and a somewhat greater tendency to appear as long lags. English-learning 2-year-olds appropriately produced 79% of short lag labials and 46% of long lag labials. In addition, 31% of labial lead models were imitated with voicing lead as would be appropriate for Spanish! English dentals show 83% correct imitations of short lags and 53% correct imitation of long lags. Lead dental stops were imitated as short lags. The velar stops were imitated much as dentals by the English-learning children. Figs. 2 and 3 show the distributions of stop voicing production for each of the language groups for each place of articulation.

All of the individual data from the 2-year-olds (excluding data produced at the wrong place of articulation) were entered in a two way analysis of variance with one between-factor (Language Experience) and two within-factors (Place of Articulation: Labial, Velar, Dental; and Voicing of Model: Lead, Short Lag, Long Lag). A significant main effect was found for language experience ($F = 17.96; \text{d.f.} 1, 13; P < 0.01$). The mean VOT produced by Spanish-learning 2-year-olds was $-7.57$ msec, while the mean VOT value for the English-learning two-year-olds was $20.84$ msec. A significant effect was also obtained for Place of Articulation ($F = 4.58; \text{d.f.} 2, 24; P < 0.05$). This effect is accounted for by a trend of the English-learning children. The Spanish-learning children did not show the same trend as manifest in the significant interaction between Language Experience and Place of Articulation ($F = 3.52; \text{d.f.} 2, 24; P < 0.05$). English-learning 2-year-olds showed mean VOT values of $8.73$, $23.58$ and $30.19$ msec for labial, dental and velar places respectively, while Spanish-learners showed mean values of $-7.4$, $-10.65$ and $-4.63$ msec for the three places of articulation. Post hoc comparisons showed that the Spanish-learners differ from English-learners at the dental ($F = 11.79, P < 0.01$) and velar ($F = 12.2, P < 0.01$) places of articulation but not at the labial place. Further, Spanish-learning children did not differ significantly in VOT across places while English-learners did ($F = 5.03, P < 0.05$). For English-learners the dentals and velars differed significantly from the labials.

A main effect for voicing was also found ($F = 11.64; \text{d.f.} 2, 24; P < 0.01$), but English and Spanish children differed on the voicing effect. This effect can be illustrated by the near-significant interaction of Language Experience with Voicing of Model ($F = 2.59; \text{d.f.} 2, 24; P < 0.06$). Planned $t$ tests revealed that as predicted, Spanish-and English-learning children differed significantly in VOT values for attempted lead stops ($X = 7.00$ and $-42.16$ msec for English and Spanish, respectively; $t = 3.88; P < 0.001$) and attempted long lag stops ($X = 41.58$ and $12.20$ msec for English and Spanish,
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(4A)

Velars

Dentals

Labials

(4B)

Velars

Dentals

Labials

△ Lead
○ Short lag
◆ Long lag

These models were produced with velar articulation

For caption see p. 328.
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(4C)

Velars

Dentals

Labials

(4D)

Velars

Dentals

Labials
(4E)

**Velars**

![Graph of Velars with VOT values ranging from 0 to 200 msec](image)

**Dentals**

![Graph of Dentals with VOT values ranging from 0 to 200 msec](image)

**Labials**

![Graph of Labials with VOT values ranging from 0 to 200 msec](image)

(4F)

**Velars**

![Graph of Velars with VOT values ranging from 0 to 200 msec](image)

**Dentals**

![Graph of Dentals with VOT values ranging from 0 to 200 msec](image)

**Labials**

![Graph of Labials with VOT values ranging from 0 to 200 msec](image)

- ▲ Lead
- ○ Short lag
- ● Long lag

*All velar lead models were imitated as alveolar*
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Velars

Dentals

Labials

Fig. 4. (A, B, C, D, E, F, G) Distribution of VOT values for imitated syllables for Spanish-speakers at three places of articulation for 7 children. Subjects A through D show evidence of having acquired the native contrast.

respectively; $t = 2.32; P < 0.05$). Spanish-learning children’s imitated lead category stops ($X = -42$ msec) also differed significantly from their imitated short lag stops ($X = 7.25$ msec; $t = 3.75; P < 0.001$), and English-learning children’s attempted short lag stops ($X = 13.9$) differed significantly from their long lag stops ($X = 41.6; t = 2.10; P < 0.05$). No significant difference was found across language groups for short lag stops.

While it is true that both the analysis of variance and overall mean values show substantial differences between Spanish- and English-learning 2-year-olds, it is not the case that all subjects showed clear distinctions between their native stop voicing categories. Of the seven Spanish-learning 2-year-olds, four showed evidence of clear category distinctions. Four of the English-learning children showed clear distinctions between short and long lag stops. Individual distributions for the seven English-learning and seven Spanish-learning children are shown in Figs. 4 and 5, respectively.
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(5A)

Velars

Dentals

Labials

(5B)

Velars

Dentals

Labials

For caption see p. 332.
(5C)

Velars

Dentals

Labials

(5D)

Velars

Dentals

Labials
VOICING IN SPANISH AND ENGLISH

(5E)

Velars

Dentals

Labials

(5F)

Velars

Dentals

Labials
Fig. 5. (A, B, C, D, E, F, G) Distribution of VOT values for imitated syllables for English-speakers at three places of articulation for 7 children. Subjects A through D show evidence of having acquired the native contrast.

GENERAL DISCUSSION

The present data reveal that by age two there are significant differences between English-learners and Spanish-learners in the imitation of syllables with stop consonants differing in voicing. In addition, by this time both language groups approach adult values for VOT. Comparison of the results of Experiments I and II suggests that one cannot accurately predict whether or not a child would have a voicing contrast at age two based on the voicing characteristics of babbling from an earlier age. Infants who, at the end of the first year, babbled considerable numbers of long lag or lead elements, seemed no more likely than those who babbled exclusively short lag elements to have a voicing contrast at age two. For infants in the first year and children at two years the preferred production was short lag. Modal values were in the short lag range for all places of articulation for infant babbling groups. Two-year-olds' errors most commonly resulted from substitution of short lag elements for lead or long lag elements.

Three of seven Spanish-learners showed significant differences at age two
between voicing categories appropriate for Spanish at each place of articulation. An additional Spanish-learner had significant voicing differences at the velar and dental places with a near-significant contrast at the labial place \((P < 0.06)\). Four English-learning 2-year-olds showed significant voicing contrasts appropriate for English at all three places of articulation.

These results are similar to those reported by Zlatin & Koeningsknecht (1976), Gilbert (1977) and Macken & Barton (1980a) for English-learning children. However, results on Spanish-learners differ from those of Macken & Barton (1980b). In a longitudinal study of the acquisition of Mexican Spanish voicing contrasts, Macken & Barton found that by age two native voicing contrasts had not been acquired by any of the children in all three articulation places. The subjects showed evidence of voicing contrasts for stop consonants only in rare cases. The 2-year-old's failure to produce appropriate voicing contrasts could be attributed to difficulty in articulating, perceptual difficulty or a faulty phonological analysis. Macken & Barton found that between the ages of two and four, learners of Mexican Spanish did distinguish in their productions between syllables normally differentiated with stop voicing contrasts in adult speech. However, children did not contrast their own syllables by voicing but rather, spirantized voiced initial position stops, while correctly producing short lag stops. The experimenters suggested that contrasts in VOT per se for stop consonants were secondary in Mexican Spanish acquisition. The primary phonemic voicing distinction was seen as first operationalized by a spirant–stop opposition. Thus by age four Mexican Spanish learners provide evidence of discrimination of adult forms but little evidence of spontaneous production of appropriate voicing categories.

Differences between the present results and those of Macken & Barton (1980b) may be due to several factors. One possible source of the discrepancy may lie in differences in methodology. Macken & Barton sampled from spontaneous speech while the analysis reported here was based on imitation of non-meaningful syllables. It is possible that the children speaking meaningfully tap into quite different mechanisms than those speaking in pure imitation. The meaningful speakers must retrieve words they pronounce from lexical memory. The storage of words in memory may well involve phonological codings that do not include all the phonetic information the child may be capable of perceiving and producing. Based in part on Macken & Barton's suggestions about spirantization, it is plausible that the children in their study may have analysed their own lexicon in such a way that all voiced obstruents are considered spirants, phonologically. Stops would presumably be derived at a later stage of development by a special rule changing the underlying spirants to voiced stops in initial position. In the meantime, the distinction between adult voiced and voiceless stops is operationalized by the child as a distinction of spirants vs voiceless stops. No voiced stop is actually produced (spirants replace them) when the child is speaking meaningfully.
and in a phonological mode. The imitation of nonsense syllables, however, might not engage the phonological restrictions against voiced stops, and the children might be able to employ a more extensive phonetic capability in producing them. The present study, which employed imitation, may have given the children particular assistance in achieving good phonetic pronunciations since the modelled voicing contrasts were produced with hyperarticulated leads and lags by the experimenter.

In order to check the possibility that meaningful speech and imitation produce different pronunciation in the children in the present study, transcripts of recordings of meaningful speech collected between 1;6 and 2;0 were examined for five of the Spanish-learning subjects. These recordings showed no instance of voicing contrasts differentiated by spirantization of the voiced member. Three of the longitudinal subjects who showed evidence of voicing distinctions in Experiment II showed appropriate use of voicing of stops some months prior to Experiment II in their spontaneous speech. From the onset of meaningful speech until the time of Experiment II spirantization was not observed. Two longitudinal subjects who had not acquired the voicing contrast by Experiment II did not evidence appropriate instances of either lead stops or spirantization prior to Experiment II. Thus there is no evidence to suggest that spirantization of stop consonants is used in spontaneous production by the Spanish-learning children studied here. The difference between the present study and that of Macken & Barton (1980), then, cannot be attributed to the difference between meaningful and imitative speech.

Another possible explanation of the differences between the studies is that there are inherent differences between Mexican Spanish and Caribbean Spanish. Although both dialects employ a stop consonant voicing distinction in initial position, there may be differences between the dialects in the extent to which underlying initial voiced stops are spirantized. Macken & Barton (1980b) report that in Mexican Spanish adult-to-child speech, 30–40% of all underlying utterance-initial voiced steps are spirantized. Hammond (1976) reports the use of spirants in obligatory environments (i.e. medially) in Cuban Spanish in Miami. Our own experience with Cuban speakers suggests that spirantization of elements that are usually produced as stops in other dialects is limited in initial position to the case of orthographic v. Thus the Mexican dialects as reported by Macken & Barton (1980b) may have more widespread spirantizations than Cuban dialects especially in non-obligatory environments.

In other regards as well, it is clear that the Cuban dialect has far fewer pronounced spirants than Mexican Spanish. Underlying final spirants and spirants occurring in underlying consonant clusters are deleted in Cuban dialects, especially in allegro speech, and often in more careful pronunciations as well. These deleted spirants of the Cuban dialect are voiceless, while the spirants that occur in place of underlying voiced stops in all dialects are voiced.
Still, the widespread deletion of spirants may produce a Cuban dialect flavour that predisposes young children to treat spirants as a weak class in general. The Mexican dialect does not evidence such a pattern, and thus the child learning that dialect may be more inclined to treat spirants as a strong class. It seems plausible that, as a result of the relative strength of spirants in Mexican Spanish, the child learning the Mexican dialect may be inclined to develop a voiced spirant category to contrast with initial-position voiceless stops, while the child learning the Cuban dialect may be predisposed to posit a voiced stop category in order to operationalize the same contrast. This reasoning is speculative, but does offer one plausible explanation for the discrepancy between the present results and those of Macken & Barton. If it is verified in further research that the overall strength of spirants in Spanish dialects affects the young child’s production of stops, it will support the position that subtle differences in linguistic environment influence the organization of the developing phonological system.

In conclusion, the present study suggests that both English-and Spanish-learners commonly show an ability to produce native voicing contrasts in imitation by the beginning of the third year of life. In the case of Spanish-learners the opposition is between lead and short lag stops while for English-learners the opposition is between short and long lag stops. In each group slightly more than half of the children demonstrated acquisition. It was not possible to predict which children in each group would be the early learners based on the distribution of VOT values in their babbling during the first year of life.

REFERENCES


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