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# Infants' Sensitivity to the Sound Patterns of Native Language Words

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Acquiring a native language involves learning about its phonetic elements and the constraints on their ordering. Our study explored this issue by examining infants' listening preferences for unfamiliar words that either observe or violate native language phonetic and phonotactic patterns. American 9-month-olds, but not 6-month-olds, listened significantly longer to words with English, rather than Dutch, sound patterns. Dutch 9-month-olds showed the opposite pattern of preferences. No preferences occurred for low-pass-filtered versions of the words, suggesting that infants were responding to phonetic and phonotactic properties rather than to prosodic ones. However, when words fundamentally differed in their prosodic organization (e.g., English vs Norwegian), even American 6-month-olds listened significantly longer to English words. 

One of the important tasks facing the language learner is to determine the underlying organization of the sound structure of the language. Not only must the child correctly identify the inventory of sounds that are used in the language, but he or she must also discover the possible orderings of these sounds in words and phrases in the language. Thus, the child acquiring English learns that although [θ] is an acceptable element in English words, [x] is not. Similarly, the same child learns that the English phonotactic ordering constraints on these elementary sound units permit [θ] at the beginning of a syllable to be followed by [r], as in [θrIfti] ("thrifty"), but not by [l], [n], or [m]. Of course, these phonotactic constraints on the order of sound elements apply to a particular domain. Sequences which are impermissible within the same

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syllable might appear elsewhere in the input. For example, the sequence [θm] occurs in a phrase like "the fif*th m*ember". Thus, in learning about the phonotactic constraints, the child must extract the regularities about the ordering of segments from the right set of contexts, in this case, the syllable.

Previous investigations of sensitivity to the phonetic and phonotactic features of native language words have concentrated largely on subjects who are considerably beyond the beginning stages of language acquisition. For instance, Brown and Hildum (1956) found that, in a noisy background, college students were better able to identify monosyllables whose initial consonant clusters were permissible under the phonotactic constraints of English, as opposed to ones which violated these constraints. Greenberg and Jenkins (1964) also tested adults in a series of experiments in which they asked subjects to scale items containing consonant clusters (many of which were impermissible in English) for their relative distance to English words. Pertz and Bever (1975) extended this line of research to adolescents and to children (9–11 years old) and found that these groups were consistent in rating items according to their psychological distance from English word structure. The youngest age for which sensitivity to the phonotactic patterns of the native language has been recorded comes from a study with nursery school children (average age = 3.7 years old) by Messer (1967). Based on a structural formula described by Whorf (1956), he selected pairs of items, one of which was a possible word in English, the other of which was not. Children were asked to judge which of the pair sounded more like a word. Not only did they correctly choose the "possible" words significantly more often than the "impossible" ones, but they also mispronounced the latter significantly more often than the former. Messer interpreted these results as an indication that the children had already absorbed the structural formula which generates English words. Interestingly enough, Whorf (1956) had speculated that children might not learn the structural formula until around 6 years of age.

Nevertheless, most of these studies were carried out more than 20 years ago. In the interim, research on infant speech perception capacities has demonstrated the existence of some pretty remarkable abilities (for reviews see Aslin, Pisoni, & Jusczyk, 1983; Jusczyk, in press (a); Kuhl, 1987; Werker, 1991). Not only are infants able to discriminate a wide variety of phonetic contrasts (e.g., Eimas, 1974; Eimas, 1975; Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Levitt, Jusczyk, Murray, & Carden, 1988; Morse, 1972; Trehub, 1973), but they are also able to compensate for changes in talkers' voices (Jusczyk, Pisoni, & Mullennix, 1992; Kuhl, 1979; Kuhl, 1983). Furthermore, young infants apparently require little or no prior experience to discriminate phonetic contrasts which do not occur in their native language (Aslin, Pisoni, Hennessy, & Perey, 1981; Lasky, Syrdal-Lasky, & Klein, 1975; Streeter, 1976; Trehub, 1976). These sorts of capacities potentially provide the means for learning any one of the world's languages. Thus, the speech perception capacities of young infants provide them with a foundation for dealing with properties that the structures of all languages share. The infant must still learn about the specific ways in which these general properties are realized in the particular native language that he or she is acquiring. In other words, the infant has to learn how the sound structure of the native language is organized.

When do infants begin to learn about the sound structure of their native language? Infants appear to be attentive to some aspects of native language sound patterns right from birth. Mehler, Jusczyk, Lambertz, Halsted, Bertoncini, and Amiel-Tison (1988) reported that newborn infants showed preferences for speech produced in their mother's native language as opposed to a foreign language. However, there is also some evidence that speech perception capacities undergo some reorganization during the latter half of the first year of life as a result of experience with the native language. Thus, sensitivity to at least some nonnative phonetic contrasts has been shown to decline between 6 and 12 months of age (e.g., Werker & Lalonde, 1988; Werker & Tees, 1984, but see Best, 1991; Best, McRoberts, & Sithole, 1988). So, although at 6 months, infants from English-speaking homes readily discriminate phonetic contrasts that occur in Hindi, but not in English; by 12 months of age, they no longer give evidence of discriminating these contrasts (Werker & Lalonde, 1988). Hence, the decline in sensitivity to foreign language contrasts suggest that infants are in the process of narrowing their focus to native language sound categories.

Two recent investigations provide further indications that infants are beginning to tune in to the sound patterns of their native language during the latter half of the first year of life. Jusczyk, Hirsh-Pasek, Kemler Nelson, Kennedy, Woodward, and Piwoz (1992) examined the sensitivity of American infants to prosodic markers of phrasal units in English. Languages vary considerably in the means by which they link together elements belonging to a particular phrase. Some languages, like English, use a strict ordering of words, whereas other languages, such as Polish, use case markers and allow word order to vary more freely. For this reason, one would expect that the language learner must discover how phrases are marked in his or her native language. Jusczyk et al. reported that American 9-month-olds, but not 6-month-olds, are sensitive to prosodic markers of boundaries of major phrasal units in English sentences. In particular, the infants listened longer to passages that were interrupted at boundaries between subject and predicate phrases than they did to comparable passages which were interrupted within the phrases. Moreover, the same pattern of results occurred in additional experiments in which the passages were low-pass-filtered to remove segmental information (while preserving the prosody), suggesting that the infants were responding to prosodic features of the passages. Evidence for a developing sensitivity to another aspect of the sound structure of the native language comes from a recent study by Kuhl, Williams, Lacerda, Stevens, and Lindblom (1992). They reported that American and Swedish 6-month-olds display sensitivity to the internal organization of certain native language vowel categories. The fact that American infants only displayed sensitivity to the internal organization of an English vowel category, and Swedish infants only for a Swedish vowel category, suggests that it develops as a result of experience with native language input.

Thus, there are a number of indications that infants are beginning to learn about native language sound patterns during the latter half of the first year. Coincidentally, this is also the time at which infants are beginning to learn about words in their native language. Although production of words prior to the first birthday is quite limited, there are indications that comprehension of words is more advanced. For example, both Huttenlocher (1974) and Benedict (1979) have noted that subjects they studied showed comprehension of several words by 10 months of age. Given that there are signs of a growing interest in words at this time, it is reasonable to ask whether they are also beginning to pick up the phonotactic patterns of words in the native language.

One way of exploring this issue is to determine whether infants treat items which follow the native language phonetic and phonotactic structure differently from ones which do not. For example, when listening to words produced by a bilingual talker, would infants attend more to ones from the native language than to a foreign language? Judging from the Mehler et al. (1988) results with newborns, the answer might appear to be obvious. However, they presented their subjects with long passages of speech that varied in much more than just the phonetic and phonotactic characteristics of words. Infants in their study could have relied on characteristics having to do with the rhythmic and intonational patterns of whole sentences, rather than the phonetic and phonotactic properties of individual words. Indeed, the fact that Mehler et al.'s subjects responded the same way to the stimuli when the phonetic and phonotactic cues were removed by low-pass filtering supports the view that they were responding to the prosodic characteristics of the utterances. In order to minimize the possible use of prosodic cues in the present study, we decided to use lists of words rather than sentences and to compare how infants respond to words from two languages that have similar prosodic characteristics—namely, English and Dutch. Both of these languages are stress-timed and display an opposition between strong and weak syllables (Reitveld & Koopmans-van Beinum, 1987). In English, stressed syllables tend to have more pitch movement, greater amplitude, and increased durations relative to unstressed syllables (Crystal & House, 1988; Ladefoged, 1975). These pitch, amplitude, and durational correlates of stress in English tend to pattern in the same way as in Dutch (Reitveld, 1988).

## Experiment 1

Our goal was to determine whether infants show signs of recognizing the phonetic and phonotactic characteristics of words in their native language. One possible indication of this would be greater attention to items that embody the phonetic and phonotactic characteristics of words in the native language as opposed to ones which do not. This tendency would follow from the fact that infants are becoming interested in the vocabulary of the native language. To explore this possibility, we had a bilingual Dutch/English talker record lists of two- and three-syllable words in each language. To minimize the possibility that infants might respond on the basis of a few highly familiar items, the words chosen from each language were low frequency, abstract words. The lists from each language contained items that were impermissible in the other language according to its phonetic and phonotactic structure. For example, the [r] in English words is very different from the [r] found in Dutch words. Whereas English allows [d] to occur in syllable-final position, Dutch does not. Similarly, Dutch allows sequences like [kn] or [zw] to begin syllables, English does not.

Our initial investigation focused on the responses of 9-month-olds because previous studies (Jusczyk, Cutler, & Redanz, in press; Jusczyk et al., 1992) have shown that infants demonstrate sensitivity to certain elements of native language sound patterns at this age. In addition, as noted earlier, there is some indication that infants this age are beginning to comprehend words (Benedict, 1979; Huttenlocher, 1974; Thomas, Campos, Shucard, Ramsay, & Shucard, 1981). Consequently, for American infants tested using the headturn preference paradigm (Fernald, 1985; Jusczyk et al., 1992), we expected that sensitivity to the phonetic and phonotactic features of the native language would be manifested in significantly longer orientation times to the English as opposed to the Dutch lists.

### *Method*

*Subjects*. Twenty-four American infants of approximately 9 months of age were tested. The infants had an average age of 38 weeks, 6 days (range: 37 weeks, 4 days to 41 weeks). Four additional infants were tested but not included for the following reasons: failed to look for an average of at least 3 s to each side (1), cried (1), parent failed to center the infant on her lap (1), and equipment failure (1).

*Stimulus materials*. The materials consisted of 16 prerecorded lists of words for each language. Each list consisted of 15 low-frequency, abstract words. No words were repeated in any of the lists. Ten of these words were two-syllables long, the remaining five words were three-syllables long. Of the 10 two-syllable words in each list, 5 contained segments or sequences of segments which are not found in the other language. Of the 5 three-syllable words in each list, 2 or 3 words contained segments or sequences of segments that were impermissible in the other language. An example of typical Dutch and English lists is shown in Table 1. The average duration of the lists was 28.28 s for Dutch, and 28.05 s for English. A paired $t$ test confirmed that there were no significant differences in duration between the Dutch and English lists ($t(15) = 0.48$).

The lists were recorded in a sound attenuated room with a Shure microphone and a Revox (A77) tape recorder. The talker was a Dutch female who had learned English as a child. Her pronunciation of the English words was checked by a native English speaker, and prior to recording, she practiced each list several times. In recording the lists, the talker alternated between Dutch and English lists. She was told to read the lists at a comfortable rate and to try to space the words equally. Each of the prerecorded lists was then digitized into a separate file on a PDP 11/73 computer using

TABLE 1
SAMPLE WORD LISTS FOR ENGLISH/DUTCH SOUND PATTERN STUDY

| English | Dutch |
|---|---|
| vacate | structuur |
| avoid | waardig |
| lengthen | geslacht |
| brutal | oprecht |
| jostle | nerveus |
| trustworthy | efferent |
| admission | revolutie |
| thistle | hersteld |
| exotic | uitsteeksel |
| lavish | woestijn |
| abundant | obstructie |
| jury | eggen |
| fluctuate | anderzins |
| usage | verwant |
| impact | lading |
| Mean duration = 28.05 s | 28.28 s |

a 12 bit A/D converter. Four of the lists from each language were chosen as practice trial lists; the remaining lists were used on the test trials.

*Apparatus*. The PDP 11/73 controlled the presentation of the lists and recorded the observer's coding of the infant's responses. The audio output for the experiment was generated from the digitized waveforms of the samples. A 12 bit D/A converter was used to recreate the audio signal. The output was fed through anti-aliasing filters and a Kenwood audio amplifier (KA 5700) to 7-inch Advent loudspeakers mounted on the sidewalls of the testing booth.

The experiment was conducted in a three-sided test booth constructed out of pegboard, with panels of 4 × 6 ft on three sides and open at the back. This made it possible for an observer to look through one of the existing holes to monitor the infant's headturns. Except for a small section for viewing the infant, the remainder of the pegboard was backed with white cardboard to guard against the possibility that the infant might respond to movements behind the panel. The test booth had a red light and a loudspeaker mounted at eye level on each of the side panels, and a green light mounted on the center panel. A white curtain suspended around the top of the booth shielded the infant's view of the rest of the room. A computer terminal and response box were located behind the center panel, out of view of the infant. The response box, which was connected to the computer, was equipped with a series of buttons that started and stopped the flashing center and side lights, recorded the direction and duration of headturns, and terminated a trial when the infant looked away for more than 2 s. Information about the direction and duration of headturns and the total trial duration was stored in a data file on the computer.

*Procedure*. The procedure was a modified version of one originally developed by Fernald (1985). Each infant was held on a parent's lap. The parent was seated in a chair in the center of the test booth. The infant completed an 8-trial familiarization phase (four lists of each type: Dutch and English) and a 12-trial test phase. The Dutch lists were consistently played through the loudspeaker on one side panel, and the English lists through the loudspeaker on the other side panel. (The side was counterbalanced across subjects.) The familiarization phase was intended to acquaint the infant with the assigned position of each type of list. The ordering of the stimuli during the test trials was random, subject to the constraint that no more than three lists of the same type could occur in a row. During the test phase, the infant heard six lists from each language.

Each trial began by blinking the green light on the center panel until the infant had oriented in that direction. Then, the center light was extinguished and the red light above the loudspeaker on one of the side panels began to flash.[1] When the infant made a headturn of at least 30° in the direction of the loudspeaker, the next list appropriate to that side began to play and continued until its completion or until the infant failed to maintain the 30° headturn for 2 consecutive s (e.g., if the infant turned back to the center or the other side, looked at the mother, the floor or the ceiling). If the infant turned briefly away from the target by 30° in any direction, but for less than 2 s, and then looked back again, the time spent looking away was not included in the orientation time. During the familiarization trials, the red light was extinguished when the list began, but during the test trials, the light remained on for the entire duration of the trial.

An observer hidden behind the center panel looked through a peephole and recorded the direction and duration of the infant's headturns using a response box. The observer was not informed as to which loudspeakers played the Dutch and English lists. This was possible because the assignment of the versions to the left or right side was determined by the computer and not revealed to the observer until the completion of the test session. The loudness levels for the samples were set by a second assistant, who was not involved in the observations, at 72 ± 2 dB (C) SPL using a Quest (Model 215) sound level meter. In addition, both the observer and the infant's parent listened over headphones to a recording of lists of randomly interspersed Dutch and English words produced by the same talker who had recorded the test stimuli. This list proved to be an excellent masking stimulus and parents and observers reported that with this background they were unaware of either the location or the nature of the stimulus on the trial.

### *Results and Discussion*

The amount of time that each infant oriented to the loudspeaker on each trial was recorded. The average looking time was 8.94 s ($SD$ = 3.34 s) for the English lists and 5.83 s ($SD$ = 2.4 s) for the Dutch lists. Twenty-two of the 24 infants had longer listening times for the English lists. A paired $t$ test confirmed that the difference in orientation times to the English and Dutch lists was highly significant ($t(23) = 5.87$, $p < .001$). Thus, the present results demonstrate that American 9-month-olds listen significantly longer to word lists composed of items following English phonetic and phonotactic patterns than to ones following Dutch patterns. One possible interpretation of these results is that the infants have learned something about the phonetic and

[1] During the familiarization trials, the blinking red light is extinguished as soon as the infant orients to the side and the list begins to play. However, during the test trials, the blinking light remains on until the trial ends. Extensive pilot testing convinced us that this is the best way to handle the lights during the procedure. Leaving the flashing light on during the familiarization trials seems to habituate the infants to the lights, and results in very short orientation times during the test trials. Moreover, the infants are also less likely to complete the full set of test trials under these circumstances.

phonotactic properties of English words. However, at this point, there are a number of possible alternative explanations for these results. First, although the prosody of English and Dutch words is similar, it could be the case that infants are responding to some subtle prosodic differences between the English and Dutch words. Second, it may be the case that the English words are simply more interesting to listen to and that infants of all ages and cultures would have responded in the same way as did the English 9-month-olds. These various possibilities were explored in the next several experiments.

## EXPERIMENT 2

One means of determining whether infants were responding to the phonetic and phonotactic properties of the words or to their prosodic characteristics is to low-pass filter the stimuli. Such a procedure has been used effectively in a number of previous studies with infants (Cooper & Aslin, 1990; Fernald, Taeschner, Dunn, Papousek, Boysson-Bardies, & Fukui, 1989; Jusczyk et al., in press; Jusczyk et al., 1992; Mehler et al., 1988). Low-pass filtering the stimuli at 400 Hz would remove most of the phonetic and phonotactic information from the words while leaving prosodic information (such as rhythm and intonation), more or less, intact. Thus, if infants respond to the prosodic characteristics of the words, they should still orient significantly longer to low-pass-filtered versions of the English words. On the other hand, if the infants do respond to the phonetic and phonotactic characteristics of the words, low-pass filtering may disrupt the preference for the English word lists.

### *Method*

*Subjects*. Twenty four American infants of approximately 9 months of age were tested. The infants had an average age of 39 weeks, 0 days (range: 35 weeks, 2 days to 42 weeks, 6 days). Three additional infants were tested but excluded for the following reasons: crying (1), and failure to complete the full set of test trials (2).

*Stimulus materials*. The same lists of words were used as in the previous experiment. However, after the conversion of digitized files to audio output by the D/A converter, the resulting signals were passed through a Krohn-Hite filter with the low-pass cutoff set to 400 Hz with an attenuation slope of 48 dB per octave. This filter level was sufficient to eliminate almost all of the distinctive phonetic information from the samples while leaving intact prosodic features such as intonation, stress, and rhythm. The filtered samples were output to the amplifier and then to the loudspeakers in the testing room.

*Apparatus and procedure*. These were the same as in the previous experiment.

### *Results and Discussion*

The amount of time that each infant oriented to the loudspeaker on each trial was recorded. The average looking time was 8.63 s ($SD = 3.43$ s) for the English lists and 8.67 s ($SD = 3.26$ s) for the Dutch lists. Overall, 11 of the 24 infants had longer looking times for the English lists. A paired $t$ test indicated that the difference in orientation times to the English and Dutch lists was not significant ($t(23) = 0.06$).

In contrast to the previous experiment, there was no indication that American infants oriented significantly longer to the low-pass-filtered versions of the English word lists. Thus, it is unlikely that the preferences observed in the previous experiment can be attributed to prosodic differences between the English and Dutch word lists. The prosodic features of the words remain after low-pass filtering, whereas most of the information about the phonetic and phonotactic characteristics of the words is missing. It is interesting to note the impact that removing the phonetic and phonotactic information had on infants' orientation times to the lists. Listening times to the low-pass-filtered versions of the Dutch word lists actually increased (8.67 s) over what they were in the previous experiment (5.83 s), whereas the listening times to the English lists were virtually unchanged (8.94 s for Experiment 1 vs 8.63 s for Experiment 2). One interpretation of this pattern of results is that the unfamiliar phonetic and phonotactic structure of Dutch may lead American infants to "tune out" these items. However, the finding of shorter orientation times to the Dutch samples also suggests another possibility—namely, that the Dutch words may simply be intrinsically less interesting or pleasing for the infants to listen to. If so, then our results would have little to do with infants' learning about the phonetic and phonotactic properties of native language words. To investigate this possibility, we decided to test a group of younger infants on the Dutch and English word lists.

## EXPERIMENT 3

As noted earlier, a number of investigations have reported that the sound patterns of the native language begin to have a noticeable impact on speech perception capacities during the latter half of the first year of life. Consequently, while 6 month olds apparently discriminate both native and nonnative contrasts with equal facility, by 10 to 12 months of age, sensitivity to certain nonnative contrasts appears to wane (Best, McRoberts, Goodell, Womer, Insabella, Klatt, et al., 1990; Best et al., 1988; Werker & Lalonde, 1988; Werker & Tees, 1984). Similarly, studies examining infants' sensitivity to certain properties of the sound patterns of their native language, have found evidence for such sensitivities in 9-month-olds, but not 6-month-olds (Jusczyk et al., in press; Jusczyk et al., 1992). For these reasons, we decided to investigate how 6-month-old American infants would respond to the English and Dutch word lists.

### *Method*

*Subjects.* Twenty-four American infants of approximately 6 months of age were tested. The infants had an average age of 26 weeks, 5 days (range: 24 weeks, 5 days to 30 weeks, 2 days). Two additional infants were tested but not included because they cried and did not complete the procedure.

*Stimulus materials, apparatus, and procedure.* These were identical to those in Experiment 1.

### *Results and Discussion*

The amount of time that each infant oriented to the loudspeaker on each trial was recorded. The average looking time was 9.39 s ($SD$ = 4.05 s) for the English lists and 9.14 s ($SD$ = 4.22 s) for the Dutch lists. Thirteen of the 24 infants had longer listening times for the English lists. A paired $t$ test indicated that this difference in orientation times to the English and Dutch lists was not significant ($t(23) = 0.37$). Thus, unlike the 9-month-olds in Experiment 1 who heard the same lists, the 6-month-olds in the present experiment did not show any tendency to listen significantly longer to the English than to the Dutch word lists. This finding undercuts the view that the Dutch lists are somehow inherently less interesting or pleasing for infants to listen to. If so, then the 6-month-olds should have behaved in the same manner as did the 9-month-olds. Instead, the pattern of results across the two experiments supports the view that the older infants have picked up information about the phonetic and phonotactic properties of native language words. To confirm this developmental trend we submitted the data from the 6-month-olds in the present study and from the 9-month-olds in Experiment 1 to an ANOVA of a 2 (Age) × 2 (Language) design. Significant effects were observed for Age ($F(1,92) = 6.69, p < .02$), Language ($F(1,92) = 5.34, p < .025$). The interaction between these two factors was marginally significant ($F(1,92)$

= 3.80, $p$ = .054) suggesting that older infants are perhaps more attentive to the phonetic and phonotactic differences between the English and Dutch words.

The pattern of results obtained across these first three experiments is certainly consistent with the view that infants begin to attend to information about the phonetic and phonotactic properties of words in their native language between 6 and 9 months of age. However, thus far we have only explored the way in which infants from English-speaking homes respond to the stimuli. In order to make a convincing case for the claim that infants have picked up information about the sound patterns of their native language, it is important to show that Dutch infants show the comparable preference for listening to Dutch words over English words. Otherwise, it could still be the case that there is simply something about the English words that attracts the attention of 9-month-olds of any language background.

## Experiment 4

The rationale behind the present experiment was to discover whether Dutch infants give evidence of responding to sound patterns that are appropriate to their native language as opposed to English. If so, this would provide further support for the view that, by 9 months of age, infants have already acquired important information about the way in which sounds are organized to form words in their native language.

We also saw the opportunity to address another interesting issue. To this point, the word lists from each language contained two different types of violations of the sound structure of the other language. One type of violation had to do with the appearance of a phone that does not appear in the other language (e.g., the consonant that begins the English word "thermal" does not appear in Dutch and the Dutch consonant that begins the word "gouda" does not appear in English). The other types of violation had to do with the phonotactic structure of the languages (i.e., there are particular sequences of phones which cannot occur together in a word in the other language). So the [kn] in the Dutch word "knevel" is not found in English, nor is the sequence [tʃ] which occurs in the English word "pitches" allowable in Dutch words. Of course, technically, when a phone appears which is not in the inventory of phones used in a particular language, the phonotactics of the language are also violated. Still it is possible that the kinds of violations that the infants are picking up might have more to do with detecting phones which do not normally occur in their native language words, rather than responding to impermissible combinations of native language phones. For this reason, we decided to redesign our stimulus materials to focus on infants' sensitivity to the native language phonotactic constraints. In particular, we redesigned our word lists in each language and removed and replaced any items which contained phones that did not also appear in the other language. This meant not using English words containing /θ/ or /r/ and Dutch words containing /r/, /sch/, /g/ or certain dipthongs. Thus, what distinguished the lists in the different languages had to do with the sequences of phones that each language allows within words.

Because the stimulus materials had been redesigned, it was necessary to determine whether American infants would continue to show longer listening times to the English lists. Accordingly, both American and Dutch 9-month-olds were tested in the present study. If the infants have acquired information about the phonotactic organization of their native language, then the American infants should orient significantly longer to the English lists, whereas the Dutch infants should orient significantly longer to the Dutch lists.

*Method*

*Subjects.* Twenty-four American and 24 Dutch infants of approximately 9 months of age were tested. The American infants had an average age of 38 weeks, 4 days (range: 36 weeks, 0 days to 41 weeks, 2 days). The Dutch infants had an average age of 38 weeks, 6 days (range: 38 weeks, 3 days to 42 weeks, 2 days). Seven additional infants (2 American, 5 Dutch) were tested but excluded for the following reasons: infant was too restless and failed to orient to the lights (3), parent failed to keep infant centered on her lap (1), infant cried (1), average looking times for each side were under 3 s (1), and experimenter error (1).

*Stimulus Materials.* For each language, 10 lists were prepared. Each list consisted of 12 low-frequency abstract words. Unlike the lists used in the previous experiments which included a large group of filler items (about 50% of the words) that did not violate constraints in the other language, more than 80% of the words in the new lists violated the phonotactic restrictions of the other language.[2] The constraints applied to sequences that were permissible in word-initial, word-final, and word-internal positions. For instance, Dutch allows word-initial clusters such as [vl] as in "vlooide", whereas English allows words to begin with [ə] as in "astound".[3] Dutch allows word-internal sequences like [lmp] as in "kalmpjes", whereas English allows [tʃ] as in "pitches". Dutch allows words to end with [mst] as in "opkomst"; English allows words to end in voiced stops such as [b] in "hubbub". An example of typical Dutch and English lists is shown in Table 2. The average duration of the lists was 21.07 s for Dutch and 21.34 s for English.

TABLE 2

SAMPLE WORD LISTS FOR ENGLISH/DUTCH PHONOTACTIC STUDY

| English | Dutch |
|---|---|
| kudos | zweten |
| aglow | vlakte |
| cubeb | kneizen |
| butane | zalmpjes |
| skutcheon | knoest |
| futile | bekomst |
| aboard | zwendel |
| cusec | toekomst |
| dudgeon | knotten |
| stewed | zwetsen |
| abound | knabbelen |
| newfangled | vangst |
| Mean duration = 21.34 s | 21.07 s |

The lists were recorded in a sound attenuated room with an ECN 959 microphone and a TCD D10 tape recorder. The talker was an American female (CB) living in the Netherlands who had learned Dutch as a child and was fluent in both languages. Her pronunciation of the Dutch words was checked by a native Dutch speaker, and prior to recording, she practiced each list several times. In recording the lists, the talker alternated between Dutch and English lists. She was told to read the lists at a comfortable rate and to try to space the words equally. Each of the prerecorded lists was then digitized into a separate file on a PDP 11/73 computer using a 12 bit A/D converter. Two of the lists from each lan-

[2] Our original intent was to include only items that violated the phonotactic patterns permitted in the other language. However, due to some miscommunications, a few phonotactic sequences which have a low frequency of occurrence in the other language were included. For example, [dw] is much more common as an initial cluster in Dutch than it is in English. Similarly, although words ending with [ə] are fairly common in Dutch, they are less so in English.

[3] One of the reviewers questioned whether the "vl" sequence in Dutch is actually pronounced with a voiced initial fricative as we have assumed, or with a voiceless fricative which would have made it sound like the English "fl" sequence. In fact, there appear to be both dialectical and socioeconomic factors which affect whether Dutch speakers are likely to produce these sequences with voiced initial segments. Both of our talkers were from the Nijmegen area where the tendency is to voice the initial segments. A trained phonetician listened to the sequences that we recorded and agreed with our own assessment that the initial "v" was voiced in the words that we presented to the infants.

guage were chosen as practice trial lists; the remaining lists were used on the test trials.

*Apparatus.* An apparatus virtually identical to the one described in Experiment 1 was constructed at the Max-Planck-Institut for Psycholinguistics for testing the Dutch infants. The only difference was that the new apparatus was equipped with a videocamera which allowed for scoring directly from a video monitor.

*Procedure.* In order to ensure comparability in judgments of orientation times, personnel at the MPI were trained by their American colleagues prior to the start of data collection for this study. Personnel from each lab visited the other lab to observe the testing procedures. Every effort was made to ensure that the procedures and criteria for judging headturns was comparable across the two laboratories.

### *Results and Discussion*

The amount of time that each infant oriented to the loudspeaker on each trial was recorded. The average looking times for the American and Dutch infants to each type of list are shown in Fig. 1. The average listening times of the American infants for the English and Dutch lists were 8.67 s ($SD$ = 3 s) and 6.44 s ($SD$ = 2.03 s), respectively. The comparable times for the Dutch infants were 6.37 s ($SD$ = 1.11 s) for the English and 7.51 s ($SD$ = 1.62 s) for the Dutch. The data for the individual subjects were submitted to an ANOVA of a 2 (Country) × 2 (Language) design. Neither the main effect of Country ($F(1,92) = 1.82$, $p > .15$) nor that of Language ($F(1,92) < 1.00$) was significant. However, the interaction between these two variables was highly significant ($F(1,92) = 7.32$, $p < .01$), reflecting the fact that the American infants listened longer to the English lists, whereas the Dutch infants listened longer to the Dutch lists. Overall, 20 of the 24 American infants had longer listening times for the English lists and 15 of 24 Dutch infants had longer listening times to the Dutch lists. Paired $t$ tests were also conducted separately on the data for the American and the Dutch infants. The listening time advantage that American infants displayed for the English lists was highly significant ($t(23) = 4.61$, $p < .001$), whereas that of the Dutch infants for Dutch, although in the right direction, was not significant ($t(23) = 1.20$, $p = .24$).

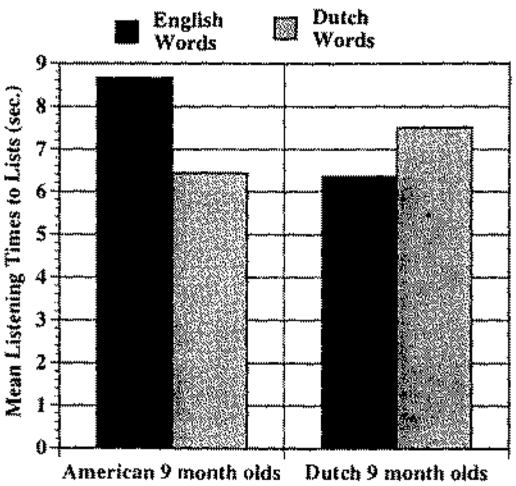


FIG. 1. Displays the average listening times of American and Dutch 9-month-olds for the lists of English and Dutch words varying only in their phonotactic properties.

Thus, the present results demonstrate that even when words vary only in terms of the sequences of phones that they contain, American and Dutch 9-month-olds tend to listen longer to items which accord with the phonotactic constraints that hold among words in their native language. The tendency to favor the native language patterns was clear for the American infants, but less so for the Dutch infants. One possible explanation for this result is that Dutch infants have considerably more contact with English—on the radio and television, and in the streets—than do American infants with Dutch. To explore this possibility a post hoc questionnaire was sent to the Dutch infants' parents in order to get information about the average hours of English input daily due to radio, TV, etc. Twenty of the 24 sets of parents returned the questionnaire. The results indicated that the infants are exposed to English input an average of

1.25 hours per day (range: 0.5 hours to 3.5 hours). Given the similarities which exist in the prosodic characteristics of the languages, it is possible that, for infants with considerable exposure to English, some potential sequences of phones may be kept open longer as candidates for word structure in Dutch. Alternatively, it is possible that since the data were collected in two different laboratories, there was something in test conditions that was responsible for the difference between the Dutch and American infants. We regard this second alternative as unlikely, given the pains we took to standardize the procedure, test setup, and scoring across the two labs.

The stimuli used in the present study differed from those used in the first three experiments. Items which contained phonetic elements that do not appear in the other language were omitted and replaced by new items. Is it possible that these changes may have brought along some other unintended changes? For example, could infants have been responding to some salient prosodic differences that distinguish the English and Dutch words on these lists? Also, unlike the lists used in the first three experiments, a greater proportion of the words on the new lists violated the phonotactic constraints of the other language. Is it possible that having a higher proportion of the words violate the phonotactic constraints of the other language makes the differences in the words from each language more salient? If so, might younger infants show sensitivity to these differences? The next two experiments were undertaken to explore each of these possibilities.

## Experiment 5

As noted in Experiment 2, one way of determining whether there is sufficient information in the prosody to distinguish the English and Dutch words is to low-pass filter them to eliminate most of the phonetic and phonotactic information. There are indications that when prosodic differences are salient, infants will continue to respond to these differences even when the stimuli are low-pass filtered (Fernald & Kuhl, 1987; Jusczyk et al., in press; Jusczyk et al., 1992). For this reason, we decided to test 9-month-olds on low-pass-filtered versions of the stimuli used in Experiment 4.

### Method

*Subjects.* Twenty-four American infants of approximately 9 months of age were tested. The infants had an average age of 39 weeks, 4 days (range: 37 weeks, 3 days to 43 weeks, 4 days). Two additional infants were tested but not included in the study because of crying.

*Stimulus materials.* The same lists of words were used as in the previous experiment. However, as in Experiment 2, the audio output was passed through a Krohn-Hite filter which had its low-pass cutoff set to 400 Hz with an attenuation slope of 48 dB per octave.

*Apparatus and procedure.* These were the same as in the previous experiment.

### Results and Discussion

The amount of time that each infant oriented to the loudspeaker on each trial was recorded. The average looking time was 6.48 s ($SD$ = 2.43 s) for the English lists and 6.02 s ($SD$ = 1.75 s) for the Dutch lists. Overall, 12 of the 24 infants had longer looking times for the English lists. A paired $t$ test indicated that the difference in orientation times to the English and Dutch lists was not significant ($t(23) = 0.89$).

Once again there was no indication that infants were able to distinguish the Dutch from English word lists on the basis of prosodic properties. Thus, as with the original stimulus set, the differences in listening times observed in Experiment 4 between the native and foreign language lists cannot be attributed to the way that infants respond to prosodic structure of the words. Rather, it appears that the phonotactic structure of the words influences the infants' listening times.

## Experiment 6

One consequence of constructing lists in which a very high proportion of the words in one language violates some phonotactic constraint in the other language is that this may draw the infant's attention to the occurrence of sequences unfamiliar to the native language. Thus, an infant who is just beginning to pick up information about the sound patterns of the native language may be more likely to detect impermissible patterns in such a context. To investigate this possibility, a new group of American 6-month-olds were tested using the new stimulus materials.

### *Methods*

*Subjects.* Twenty-four American infants of approximately 6 months of age were tested. The infants had an average age of 26 weeks, 6 days (range: 24 weeks, 6 days to 28 weeks, 0 days). Three additional infants were tested but not included because of crying (1) or experimenter error (2).

*Stimulus materials, apparatus, and procedure.* These were the same as in Experiment 4.

### *Results and Discussion*

The amount of time that each infant oriented to the loudspeaker on each trial was recorded. The average looking time was 8.32 s ($SD$ = 3.19 s) for the English lists and 7.93 s ($SD$ = 2.89 s) for the Dutch lists. Twelve of the 24 infants had longer listening times for the English lists. A paired $t$ test indicated that this difference in orientation times to the English and Dutch lists was not significant ($t(23) = 0.64$).

So once again there was no indication that 6-month-old Americans listen longer to the English words than to the Dutch words. It seems likely that the preferences which the 9-month-olds show for the native language words has to do with information that they have picked up about the sound structure of native language words. In the studies that we have conducted thus far, the distinguishing characteristics of the native language words have involved their phonetic and phonotactic structure. Hence, it appears that it is this aspect of the native language structure that infants are acquiring between 6 and 9 months of age.

Of course, there are other dimensions along which the sound patterns of native and nonnative words are distinguished. Most notably, the prosodic characteristics of words differ from language to language. English and Dutch are stress-timed languages wherein strongly accented syllables alternate with weakly accented, often reduced, syllables. By comparison, French is syllable-timed; syllables are not reduced and each receives approximately the same amount of stress. In English, stressed syllables typically have higher pitch, longer durations and greater loudness, whereas in Norwegian, stressed syllables are actually lower in pitch than are unstressed syllables (Peters, in press). In a language like Polish, syllable stress is said to be fixed because it almost invariably occurs on the penultimate syllable. In other languages, such as Russian, the location of stress is not tied to a fixed location within words.

As noted earlier, there is evidence that infants are sensitive to sentence-level prosodic differences between native and nonnative utterances from an early age (Mehler et al., 1988). However, Mehler et al. did not investigate whether infants are sensitive to native vs nonnative language stress differences at the level of words. Nevertheless, there is abundant evidence that infants can discriminate differences between word level stress patterns (Jusczyk & Thompson, 1978; Karzon, 1985; Kuhl & Padden, 1982; Morse, 1972; Spring & Dale, 1977). In this sense, infants certainly have the capacity to perceive the kinds of word stress differences which could help distinguish native from nonnative language words. But, merely discriminating these differences is not equivalent to learning to identify the patterns that are characteristic of one's native language. When does learning about ing the lists, the talker alternated between Norwegian and English lists. She was told to read the lists at a comfortable rate and to try to space the words equally. Each of the prerecorded lists was then digitized into a separate file on a PDP 11/73 computer using a 12 bit A/D converter. Four of the lists from each language were chosen as practice trial lists; the remaining lists were used on the test trials.

*Apparatus and procedure.* These were the same as in the previous experiments.

### *Results and Discussion*

The amount of time that each infant oriented to the loudspeaker on each trial was recorded. The average looking times were 9.15 s ($SD$ = 1.67 s) for English and 6.91 s ($SD$ = 1.47 s) for Norwegian. Fifteen of the 24 infants had longer looking times for the English lists. A paired t-test confirmed that the difference in orientation times to the English and Norwegian lists was significant ($t(23) = 3.10, p < .01$).

In contrast to the performance of the 6-month-olds who listened to the Dutch and English lists, 6-month-olds in the present study did listen significantly longer to the English word lists than they did to the Norwegian lists. One possible explanation for this difference is that the English and Norwegian words differ considerably in their prosodic characteristics. Perhaps, infants begin learning about characteristic prosodic patterns of words in their native language before they begin learning about the typical phonetic and phonotactic features of words. However, as noted above, there are also some phonetic and phonotactic differences between English and Norwegian. Moreover, these differences are not the same ones as occur between English and Dutch. Is it possible that the phonetic and phonotactic differences between English and Norwegian are simply more salient for 6-month-olds than were the English and Dutch differences? The next experiment was conducted to investigate this issue.

## Experiment 8

If prosodic information is important to 6-month-olds' detection of differences between the English and Norwegian lists, then the preference for the English word lists should remain even when the lists are low-pass filtered to remove the phonetic and phonotactic information. On the other hand, if infants are relying on the differences in the phonetic and phonotactic patterns of the words, then the preference for the English word lists should disappear after low-pass filtering.

### *Method*

*Subjects.* Twenty-four American infants of approximately 6 months of age were tested. The average age of the infants was 26 weeks, 3 days (range: 23 weeks, 5 days to 28 weeks, 4 days). Three additional infants were tested but not included because of crying (1), sleeping (1), and experimenter error (1).

*Stimulus materials.* The same stimulus lists were used as in Experiment 7 except that the audio output was low-pass filtered at 400 Hz (as described in Experiments 2 and 5).

*Apparatus and Procedure.* These were the same as used in the previous experiments.

### *Results and Discussion*

The amount of time that each infant oriented to the loudspeaker on each trial was recorded. The average looking time was 7.90 s ($SD$ = 3.29 s) for English and 6.62 s for Norwegian ($SD$ = 2.8 s). Eighteen of the 24 infants had longer looking times to the English lists. A paired $t$ test indicated that the difference in orientation times to the English and Norwegian lists was significant ($t(23) = 2.20, p < .05$). Thus, contrary to what happened when low-pass filtering was applied to the English and Dutch lists, infants in the present study continued to show significantly longer orientation times to low-pass filtered versions of English as these kinds of patterns occur relative to learning about the phonetic and phonotactic characteristics of native language words? The next two studies begin to explore this issue.

## EXPERIMENT 7

As noted earlier, one reason for comparing responses to English and Dutch words in the earlier studies had to do with the fact that the chief differences between words in these languages tend to be phonetic and phonotactic rather than prosodic. There are other Teutonic languages which contrast sharply to English in the prosodic characteristics of words. One of these languages is Norwegian. In contrast to English, pitch often rises on the final syllable of Norwegian words (Haugen & Joos, 1972). Also, unlike English words, pitch is higher in Norwegian for unstressed than for stressed syllables (Peters, in press). In contrast to English, words of Romance or Greek origin (e.g., ''nasjon,'' ''student,'' ''politkk,'' "meieri") are stressed on their last syllable. Norwegian and English also differ in terms of their phonetic and phonotactic characteristics. For example, Norwegian contains vowels such as [y] and [ø] which do not appear in English words, and English has segments such as [θ] and [w] which are not found in Norwegian. However, the main focus of the present study has to do with the prosodic differences which exist between English and Norwegian words. In particular, when do infants respond to prosodic patterns characteristic of native language words? Do they become sensitive to such properties only when they also begin learning about the phonetic and phonotactic characteristics of words, or does sensitivity to the prosodic features follow a different developmental course? As a first step towards understanding this issue, we decided to test 6-month-old Americans on lists of English and Norwegian words.

### *Method*

*Subjects.* Twenty-four American infants of approximately 6 months of age were tested. The infants had an average age of 26 weeks, 6 days (range: 23 weeks, 4 days to 29 weeks, 6 days). Three additional infants were tested but not included for the following reasons: mother interfered by turning the infant towards the loudspeaker (1), infant was too restless to test (1), looking times were under 3 s to both sides (1).

*Stimulus material.* Sixteen lists of 15 low-frequency words were created for each language. No words were repeated in any of the lists. As in Experiment 1, 10 words in each list were two-syllables long and the remaining 5 words were three-syllables long. An example of typical Norwegian and English lists is shown in Table 3. The average duration of the lists was 22.22 s for Norwegian, and 22.17 s for English. A paired $t$ test confirmed that there were no significant differences in duration between the Norwegian and English lists ($t(15) = 0.20$).

The lists were recorded in a sound attenuated room with a Shure microphone and a Revox (A77) tape recorder. The talker was a Norwegian female who had learned English as a child. Her pronunciation of the English words was checked by a native English speaker, and prior to recording, she practiced each list several times. In record-

TABLE 3
SAMPLE WORD LISTS FOR ENGLISH/NORWEGIAN SOUND PATTERN STUDY

| English | Norwegian |
|---|---|
| withering | pragmattsk |
| ardent | fasan |
| nation | nasjon |
| enable | gamlemor |
| judicious | myndighet |
| mention | nevne |
| chasten | verdi |
| escapade | bestandig |
| abstract | skille |
| zebra | tjene |
| justice | kilde |
| implosion | eksplosjon |
| tarry | minne |
| thermal | termos |
| wealthy | kjenne |
| Mean duration = 22.17 s | 22.22 s |

opposed to Norwegian words. This suggests that the prosodic differences between English and Norwegian words are quite salient for the American 6 month olds. Of course, it is difficult to say whether infants listening to the unfiltered versions of the lists might also attend to phonetic and phonotactic differences. The size of the looking time advantage for the English lists in the present experiment was only 1.28 s as compared to 2.24 s in Experiment 7. We submitted the data from both experiments to an ANOVA of a 2 (Experiment) × 2 (Language) design. However, only the main effect of Language was significant ($F(1,92) = 7.67$, $p < .01$). Neither the main effect of Experiment ($F(1,92) = 1.49$, $p > .20$) nor the interaction between Experiment and Language ($F(1,92) < 1.00$) approached statistical significance. Thus, if the infants in Experiment 7 were using information about the phonetic and phonotactic properties of the native language words, it was not apparent in the data analyses.

## General Discussion

The present study demonstrates that, during their first year of life, infants are beginning to pick up information about the sound patterns characteristic of words in their native language. In particular, the infants displayed significant preferences for listening to words which observe the phonetic, phonotactic, and prosodic organization of the native language. That these preferences are the result of increasing familiarity with the sound patterns of the native language is suggested by the fact that, when listening to exactly the same materials, Dutch and American 9-month-olds tended to listen longer to words from their native language. In the case of the Dutch and English words, 9-month-olds appear to be sensitive to phonetic and phonotactic properties. This is shown by the fact that when such information is eliminated by low-pass filtering, infants show no preference for the native over the nonnative language words. Moreover, even when the items were chosen to exclude words with phonetic segments that do not appear in the other language, the 9-month-olds still responded to phonotactic differences between the English and Dutch items. By comparison, the data from the experiments involving English and Dutch words provide no indication that 6-month-olds respond to the phonetic and phonotactic properties. However, the 6-month-olds did respond to differences between native and nonnative language words when they were distinguished by their prosodic features. Thus, American 6-month-olds listened significantly longer to English words than they did to Norwegian words. Furthermore, this preference held even when the items were low-pass filtered to remove phonetic and phonotactic cues while leaving the prosodic information intact. The implication of these results is that sensitivity to aspects of the prosodic structure of native language words may develop sooner than sensitivity to certain phonetic and phonotactic properties. Certainly, this tendency is in line with claims by some such as Bolinger (1965) that the prosodic elements of speech come first for the child.

It is interesting, though perhaps not surprising, that sensitivity to native language sound patterns is occurring at around the same time that other investigators have noted a decline in sensitivity to certain phonetic contrasts that do not appear in the native language (Best, 1991; Werker & Lalonde, 1988; Werker & Tees, 1984). Both kinds of phenomena may be part of a process whereby the perceptual capacities become reorganized to provide for more effective recognition of native language words in fluent speech perception (Jusczyk, 1992; in press (b)). Thus, infants may begin to concentrate more closely on those sound patterns which regularly occur in the speech they hear around them. This sublexical knowledge may provide the basis for the development of a lexicon. Certainly, it is at this point in development that infants are beginning to learn about words and to develop a lexicon for speaking and understanding the native language. Of course, in parallel with developing an effective representation of the sound patterns of words, the child also needs to learn about their meanings.

As the lexicon develops and becomes further organized, it seems likely that infants would also begin to show sensitivity to some of the regularities of frequent sound patterns within their native language. Recent investigations in our laboratories suggest that this is the case. For instance, Jusczyk, Cutler, and Redanz (in press) found that 9-month-old American infants are sensitive to the predominant stress pattern of English words. Specifically, the infants listened significantly longer to English words following a Strong/Weak stress pattern than words with a Weak/Strong pattern, even though both types of patterns are permissible in the language. More recently, Friederici and Wessels (submitted) found that 9-month-old Dutch infants listen longer to monosyllabic nonwords that contain phonetic sequences that are phonotactically legal within the language as opposed to ones which are phonotactically illegal (i.e., word onset clusters vs word offset clusters). This sensitivity to the phonotactic structure of words in the native language was demonstrated when nonwords were presented in isolation, but also when presented in connected speech as long as the context made minimal attentional demands. By comparison, there was no indication that 6 month olds display a similar sensitivity to phonotactically illegal clusters. In another study, Jusczyk, Charles-Luce and Luce (in preparation) found that, even among phonotactically legal sequences, 9-month-old American infants appear to be picking up information about the fact that certain phonetic sequences are more likely to occur in words than others. Specifically, 9-month-olds listen longer to monosyllables that embody frequently occurring phonetics sequences than they do to monosyllables containing less frequently occurring sequences. Taken together, these results suggest that between 6 and 9 month of age, infants are picking up considerable information about the sound structure of words in the native language. Moreover, it appears that they are also starting to use this knowledge to segment the auditory input into word-like units.

Hence, there is a growing body of evidence that suggests that infants are becoming attuned to the sound patterns of their native language during the latter half of the first year of life. Indeed, it looks as though infants are beginning to pick up the kinds of regularities about sound patterns of native language words that investigators twenty years ago believed did not develop until considerably later in the language acquisition process (Messer, 1967; Pertz & Bever, 1975; Whorf, 1956). At the same time, it should be noted that the recent studies with infants, including the present one, have only just begun to explore the way in which sensitivity develops to the sound patterns of the native language. Comparisons have been made only among a very few of the world's languages, and only for some of the dimensions along which sound patterns differ. In the case of the reported declines in sensitivity to nonnative phonetic contrasts, it has already been noted that not all such contrasts are affected (Best et al., 1988). In the same way, it is likely that sensitivity to all aspects of native language sound patterns does not develop at once. Only systematic comparisons of sensitivity to the sound patterns of a number of different languages is likely to reveal the way in which the developmental process unfolds. Nevertheless, the results of the present study reveal that sensitivity to at least some aspects of native language sound structure is developing early in the latter half of the first year of life.

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