Young Infants' Long-Term Auditory Memory: Evidence for Changes in Preference as a Function of Delay

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Infants' preferences for a novel or familiar nursery rhyme were examined as an index of long-term memory. One- to 2-month-old infants' preferences were tested, using a nonnutritive sucking, discrimination-learning procedure, at 1, 2, or 3 days after the last of multiple familiarization sessions. A consistent novelty preference was observed at the 1-day retention interval, no consistent preference occurred at the 2-day interval, and a familiarity preference was found following the 3-day interval. This pattern of results is consistent with attentional preference models which interpret novelty and familiarity preferences as reflecting the discrepancy between an external stimulus and the infant's representation of the stimulus. The findings also reveal that infants as young as 1 month of age encoded and subsequently recognized a repeatedly experienced nursery rhyme after a 3-day retention interval.

Keywords: human infants; memory; speech; auditory preferences

Studies of young human infants' memory functioning have revealed that they encode details of their visual environments and that they retain attributes of these experiences over lengthy delays (Bahrick & Pickens, 1995; Bushnell, McCutcheon, Sinclair, and Tweedlie, 1984; Greco, Rovee-Collier, Hayne, Griesler, & Earley, 1986; Rovee-Collier, 1993; Rovee-Collier & Hayne, 1987). However, few studies have directly examined infants' memory for naturalistic auditory stimuli such as voices and running speech. The absence of research in this area is particularly striking in contrast to the amount of infant speech perception research which has been conducted (Aslin, Pisoni, & Jusczyk, 1983), and given recent evidence for the influence of early linguistic experience on infants' speech perception (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Mehler et al., 1988; Stern, Spieker, & MacKain, 1982; Werker & Lalonde, 1988; Werker & Tees, 1984).

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The present study examined young infants' memory for a previously experienced speech passage. Memory may play an especially important role in language acquisition processes; during the 1st year of life, the infant is faced with the tasks of learning the meaningful units of the native language, associating meaning with these units, as well as producing them in appropriate contexts. Retention of this auditory information is necessary for both comprehending and producing the native language.

There is some evidence that infants under 4 months of age retain short phonetic segments over long-term intervals. Ungerer, Brody, and Zelazo (1978) demonstrated that 4-week-olds recognized bisyllabic words when tested at 14 and 42 hr after the last of 13 daily familiarization episodes. Newborns also retained similar speech sounds for a 24-hr period (Swain, Zelazo, & Clifton, 1993). Two-month-old infants discriminated syllables that differed by a single phonetic feature (Jusczyk, Kennedy, & Jusczyk, 1995) and they discriminated one sentence from another that differed by only a single phoneme (Mandel, Jusczyk, & Kemler Nelson, 1994) when a 2-min interval separated presentation of the familiarization and the test stimuli. Four-month-olds also listened longer to their own names than to other names matched on number of syllables and stress pattern (Mandel, Jusczyk, & Pisoni, 1995), suggesting that they recognized these linguistic stimuli.

Evidence for long-term recognition of a lengthy speech passage has been demonstrated only with newborn infants. Newborns preferred a speech passage that had been repeatedly read by their mothers during the last 6 weeks of pregnancy over a novel speech passage when tested 3 to 5 days after the last prenatal familiarization episode (DeCasper & Spence, 1986). Strong evidence for a memory interpretation of these results was provided by contrasting the results of the prenatal experience group with a control group; each control subject was matched to an experimental subject on age, gender, and baseline sucking pattern, and was presented the same stimuli and procedure as each experimental subject. The control group did not show the same preference pattern as the experimental group, indicating that prior experience with the speech passage accounted for the preferences of the experimental group subjects.

The few studies that have examined infants' memory for acoustic information have not systematically tested infants' responsiveness at multiple retention intervals. Consequently, little information is available concerning the length of time that auditory stimuli are retained or whether accessibility of auditory memories decreases as a function of time as does infants' retrieval of visual information (Bahrick & Pickens, 1995; Rovee-Collier & Sullivan, 1980). Research that has examined infant memory functioning using the mobile conjugate-reinforcement paradigm has consistently revealed that 2- and 3-month-old infants' retrieval of memories for visual information decreases as a function of retention interval (for reviews see Rovee-Collier, 1991; Rovee-Collier & Hayne, 1987). Three-month-old infants, for example, produce a high rate of foot kicking, a previously learned response, in the presence of the training mobile for 3 days following training. Responding gradually decreases across subsequent days so that infants respond at baseline levels in the presence of the training mobile at 14 days, indicating that the memory is not readily accessible after these longer delays (Rovee-Collier, Enright, Lucas, Fagen, & Gekoski, 1981). Evidence that these memories are still available as long as 28 days after training has been provided by demonstrations that infants' memories are reactivated when they are presented the familiar mobile in a priming procedure (Rovee-Collier & Hayne, 1987).

Studies of infant memory that have employed habituation and preferential-looking procedures have reported a different response pattern as a function of time. Swain et

al. (1993) found that newborns were more likely to respond to a novel speech stimulus than a familiar one 24 hr following habituation to that stimulus, indicating that they retained this auditory information for 24 hr. Bahrick and Pickens (1995) assessed 3-month-olds' long-term memory for object motion; infants were habituated to an object moving in a horizontal or a circular motion and their retention of this information was tested at varying intervals using a paired-comparison procedure. Three-month-old infants preferred a novel stimulus at 1 min, the shortest interval tested, while they preferred the familiar stimulus at 1- and 3-month intervals. Null preferences were obtained at intermediate intervals of 1 day and 2 weeks. The different response patterns across time that have been obtained in the mobile conjugate-reinforcement paradigm and habituation/preferential-looking procedures presumably reflect different encoding and/or retrieval demands presented by each paradigm, as well as the differential reinforcement value that may be afforded by contingent mobile movement (Rovee-Collier, 1991). Both procedures, however, provide evidence that young infants' accessibility of memory attributes decreases as a function of time.

The response pattern reported by Bahrick and Pickens (1995) is consistent with attentional preference models that propose that infants' attention to novel or familiar stimuli is a function of the discrepancy between the stimulus and the representation stored in memory (Cohen & Gelber, 1975; Hunter & Ames, 1988; Sokolov, 1969; Wagner & Sakovits, 1986). According to these models, if infants' preferences are tested while they are in the process of encoding or constructing a representation, then they attend more to the familiarization stimulus than to a novel stimulus (Hunter & Ames, 1988). However, once encoding is complete, and an internal representation of the stimulus has been formed, infants then attend more to a novel stimulus. Shifts in attentional preferences in the reverse direction, from novelty to familiarity, are predicted as a function of delay between end of familiarization and test as memory attributes decrease in strength or "deconstruct" (Wagner & Sakovits, 1986). As memory attributes decrease in strength, the representation becomes increasingly discrepant from the external stimulus, and infants should increasingly sample the previously experienced stimulus.

The present study examined 1- to 2-month-old infants' ability to retain naturalistic speech across long-term intervals. Because there is evidence that speech is a salient stimulus for infants at this age (Papousek, Papousek, & Haekel, 1987), retention of speech information may mediate infants' responsiveness to linguistic input. In the present study, each infant heard a nursery rhyme read by his/her mother during two daily episodes beginning at an average postnatal age of 5 weeks and continuing for 14 days. Infants' preferences for the familiar or a novel nursery rhyme were assessed using a nonnutritive sucking, discrimination-learning procedure conducted 1, 2, or 3 days after the last familiarization session. Previous research examining memory performance of 2-month-olds has shown that they retain specific details of their training context (Hayne, Greco, Early, Griesler, & Rovee-Collier, 1986) and a learned contingency for 24 hr following two consecutive days of training (Greco et al., 1986), but they do not retain the contingency for 3 days (Greco et al., 1986). The present study will examine if 1- to 2-month-old infants retain auditory attributes for comparable intervals.

Changes in infants' preferences across the three retention intervals were also examined to determine if infants' accessibility of auditory attributes decreases over time as has been shown to occur with visual attributes (Bahrick & Pickens, 1995; Rovee-Collier & Sullivan, 1980). The familiarization and test procedures used in the present research are similar to standard habituation and preferential-looking procedures. Consequently, a pattern of preferential responding similar to that reported by Bahrick and Pickens

(1995) would be expected. If attributes of the nursery rhyme are well represented and readily accessible at 1 day following the last of multiple familiarization episodes, preference for the novel nursery rhyme should be observed. Additionally, if memory attributes are becoming less accessible from 1 to 3 days, then a shift in preference from novel to null to familiar should begin to occur across this period.

Method

Subjects

Twenty-four infants (12 males, 12 females) and their mothers provided experimental data for this study. Eight infants were tested at each of the three retention intervals. Infants were 7 weeks postnatal age at test (r = 32–86 days, M = 49 days, SD = 11.61) and were healthy full-terms with birth weights between 2500–3900 g. Mothers and infants were recruited from local hospital nurseries and childbirth preparation classes.

An additional 17 mothers and infants participated in the daily familiarization sessions but these infants did not provide experimental session data. Three infants were fussy, 2 infants refused or did not produce adequate pressure on the pacifier, and 9 infants did not maintain a quiet, alert state. Data from 3 infants was not included because the mothers did not return a completed logbook.

Familiarization Stimuli and Procedure

Mothers were randomly assigned one of two nursery rhymes and instructed to recite the assigned passage to their infants in the manner they typically used when speaking to their infants. They were provided written and verbal instructions which specified that they recite the nursery rhyme four times during each of two daily readings for 14 days. Each mother was given a logbook and asked to record the date and time of each reading episode as well as comments regarding the baby's behavior during each reading episode. The lengthy familiarization period was selected in order to provide sufficient opportunities for encoding of the auditory stimulus by infants; previous research has indicated that 14 daily familiarization sessions were sufficient for encoding of auditory stimuli by human perinates (Panneton, 1985). The mothers of the infants who completed the experimental session recited the nursery rhyme twice daily for a mean of 12.6 days or 25.21 different episodes (SD = 4.7).

The speech passages presented to infants were the nursery rhymes "Humpty Dumpty" and "A Crooked Life" from the book *Mother Goose & More: Classic Rhymes with Added Lines* (Hickey, 1990). The two rhymes differ in meter and syllable stress patterns and they contain different distributions of specific articulatory attributes. For example, the rendition of "Humpty Dumpty" includes 19 instances of bilabial stops (/p/ & /b/) and 17 instances of velar stops (/k/ & /g/), while "A Crooked Life" contains only three instances of bilabial stops but 43 velar stops.

Experimental Stimuli

The test stimuli consisted of digitized versions of "Humpty Dumpty" and "A Crooked Life" recorded by a mother while reciting the rhymes to her 6-week-old infant. The recordings were made using a Marantz PMD 201 cassette recorder and a Sony cardioid microphone. The nursery rhymes were digitized at a sampling rate of 20 kHz

at 8-bit resolution and were stored on the computer hard drive. These speech stimuli were presented at an intensity of 70–75 dB SPL (A-weighting) through the speaker monitor that was located 60 cm in front of the infant.

Two auditory–visual discriminative stimuli were presented via a 22.86-cm color monitor placed 60 cm from the infant. The discriminative stimuli consisted of either a digitized sample of a male voice producing the phoneme /a/ or /i/ paired with either a black-and-white bullseye or a 3 × 3 checkerboard, which were created using a digital paint software program.

Experimental Design and Procedure

Infants' preferences for the novel or familiar nursery rhyme were tested at one of three retention intervals; retention intervals were defined as the length of time between the final maternal reading episode and the test session. Eight infants were tested at each retention interval of 1 day (M = 22.85 hr, SD = 5.17 hr), 2 days (M = 43.25 hr, SD = 3.25 hr), or 3 days (M = 69.94 hr, SD = 10.1 hr). Each infant was brought to the lab by a parent; sessions were begun when infants achieved a quiet, alert state. Infants were seated in an infant seat that was placed on a table. The computer monitor which presented the stimuli was 60 cm directly in front of the infant at eye level. A nonnutritive nipple was held in the infant's mouth by an experimenter who stood behind and to the right of the infant. The experimenter was blind to the infant's assigned rhyme and listened to simultaneous recordings of both nursery rhymes over headphones during the procedure in order to mask the experimental stimuli. The nipple was connected with tygon tubing to an Omega PX161-027 pressure transducer, which detected positive sucking pressure exerted on the nipple. The transducer signal was input to the computer, which recorded infant sucking, controlled the experimental procedure, and presented the discriminative stimuli and reinforcers.

Infant sucking was reinforced in a discrimination learning procedure adapted from that used by Spence and DeCasper (1987) and Moon and Fifer (1990). In the absence of sucking, one of two combination auditory–visual discriminative stimuli was presented every 4 s. Sucking exceeding a positive pressure of 20-mm Hg in the presence of one discriminative stimulus (e.g., bullseye—male voice producing /a/) was reinforced with the digitized version of the familiar rhyme, that is, the rhyme read by the mother and the associated visual stimulus (e.g., bullseye). The nursery rhyme was presented contingent on the onset of sucking and ended when 1 s elapsed without a suck. The visual component of the discriminative stimulus also remained on the monitor during presentation of the auditory reinforcer. A sucking burst was defined as a series of sucks separated from one another by less than 1 s. Sucking begun during the alternate discriminative stimulus, (e.g., checkerboard—male voice producing /i/), was reinforced with the novel nursery rhyme and the visual component of this discriminative stimulus remained on the screen for the duration of the nursery rhyme.

Each discriminative stimulus was presented twice during each of 10 blocks of trials (or 20 times each during each session), with the two presentations of each discriminative stimulus randomly ordered during each block of four trials. Within each block, each discriminative stimulus was paired once with (and, if sucking occurred, reinforced with) the first half of one nursery rhyme and paired once with the second half of that nursery rhyme. For example, the discriminative stimulus formed by pairing the visual checkerboard and the auditory stimulus /a/ was presented twice within each block. Sucking in the presence of one of the two presentations of this stimulus was reinforced with

the first half of one nursery rhyme, for example, "Humpty Dumpty", while sucking in the presence of the other presentation of this stimulus was reinforced with the second half of the same nursery rhyme. The time required for complete presentation of each half of each rhyme was 10 s. The second discriminative stimulus, for example, bullseye—/i/, was also presented twice within each block, and each presentation of this stimulus was paired with either the first half or the second half of the other nursery rhyme. This manipulation ensured equal opportunities for accessing both halves of each rhyme and was designed to preclude the possibility that only the first stanza of the rhyme would be heard during the experimental session by infants who produced short sucking bursts.

The pairings of the auditory and visual components of the discriminative stimuli were counterbalanced to control for the possibility that a specific combination of auditory and visual stimuli would elicit differential responding. The nursery rhyme reinforcer associated with each discriminative stimulus was also counterbalanced, creating four experimental conditions. In the final sample of subjects reported here, at least 3 subjects were assigned to each counterbalanced condition. "Humpty Dumpty" served as the familiar rhyme for 10 of the final subjects, while "Crooked Life" was the familiar rhyme for the remaining 14 subjects.

Results

The number of sucking bursts reinforced with the familiar and novel nursery rhymes in Blocks 2-10 served as the dependent variable. Sucking bursts in Block 1 were not included because this block served as an adjustment period for infants. There were 36 opportunities to produce a sucking burst and acquire reinforcement; the frequency of sucking bursts produced by individual infants ranged from 12 to 36 (M = 21.33, SD = 5.55).

A preliminary analysis was conducted to examine whether infants listened more often to one rhyme during the experimental session regardless of their previous experience. A matched-pairs t test revealed that the frequencies of sucking bursts that were reinforced with each nursery rhyme were not significantly different, $t(23) = 1.31$ ("Humpty Dumpty" M = 11, "A Crooked Life" M = 10.25). A second analysis examined if infants tested at each of the three intervals had equal amounts of experience with their assigned nursery rhyme. The number of reading episodes reported by each infant's mother was entered into an ANOVA in which retention interval (1, 2, or 3 days) served as the between subject factor. No significant effect of retention interval resulted; the mean number of reading episodes for the 1-, 2-, and 3-day groups were 24.63, 23.38, and 27.63, respectively.

The frequencies of sucking bursts produced by each infant that were reinforced with the familiar and novel nursery rhymes were entered into a 3 × 2 mixed ANOVA in which retention interval (1, 2, or 3 days) served as the between subject factor while rhyme (familiar vs. novel) served as the within subject factor. A significant interaction of retention interval and rhyme resulted, $F(2,21) = 5.9$, $p < .01$, as shown in Figure 1. Analyses of simple effects of rhyme at each level of retention interval were conducted using the mean square error of the omnibus F obtained from the ANOVA. Infants tested at the 1-day retention interval (n = 8) produced more sucking bursts that were reinforced with the novel rhyme (M = 12) than the familiar rhyme, M = 10.25, $F(1,21) = 4.24$, $p = .054$). Infants in the 3-day group (n = 8) produced more responses that accessed the familiar than the novel rhyme, Ms = 12.13 & 9.75, respectively, $F(1,21) = 7.81$, $p < .025$. There was no difference in the number of sucking bursts

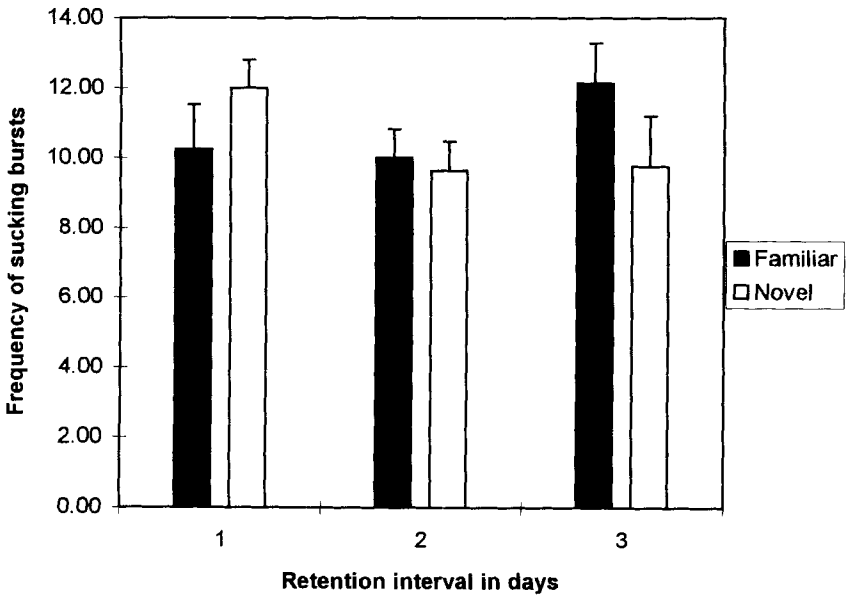

Fig. 1. Mean frequencies (and standard errors) of sucking bursts reinforced with the familiar and novel nursery rhymes at 1-day (n = 8), 2-day (n = 8), and 3-day (n = 8) retention intervals.

reinforced with each of the two rhymes for infants in the 2-day retention interval, n = 8. familiar M = 10, novel M = 9.63. $F(1,21) < 1.0$.

Because the ages of the infants in this sample ranged from 32 to 86 days, an ANCOVA was conducted to ensure that age-related differences in responding did not account for the differences in the direction of preference across retention intervals. Infant age in days served as a covariate, while retention interval (1, 2, or 3 days) was the between subject factor and nursery rhyme (familiar vs. novel) was entered as a within subject factor. No effects of age were found, Fs < 1.0.

Discussion

Seven-week-old infants who had been repeatedly familiarized with a nursery rhyme preferred the novel nursery rhyme when tested at a 1-day delay following familiarization, they exhibited no consistent preference at 2 days, and they preferred the familiar rhyme at the 3-day retention interval. This pattern of preferential responding can be interpreted as reflecting changes in the accessibility of the representation in long-term memory, and is consistent with predictions based on attentional preference models (Hunter & Ames, 1988; Wagner & Sakovits, 1986). According to these models, infants prefer and attend to novel stimuli if there is little discrepancy between the memory of the previously experienced and the external stimulus, while familiarity preferences are observed if discrepancy exists between the representation and the external stimulus (Hunter & Ames, 1988; Wagner & Sakovits, 1986). When infants in the present study were tested at 1-day intervals, when the rhyme was well represented in memory, infants preferred to hear the novel rhyme. This finding is consistent with results of other studies that have reported novelty preferences at 24-hr delays for both visual (Martin, 1975) and

auditory stimuli (Swain et al., 1993). However, as the memory attributes became increasingly inaccessible, or discrepant from the external stimulus, infants attended more to the familiar stimulus, initially resulting in no consistent preference for either stimulus at 2 days and finally resulting in a significant preference for the familiar stimulus at 3 days. These results suggest that some subset of attributes of the speech stimulus are retained for 3 days; if all attributes were inaccessible at 3 days, then no consistent preference for the familiar stimulus would result.

Bahrick and Pickens (1995) found a similar pattern of preferences and proposed a four-phase function reflecting infant memory as an extension of these attentional-preference models. Phase 1 reflects recent memory and is characterized by novelty preferences, while Phase 3 reflects remote memory and is characterized by familiarity preferences. Phase 2, a transitional phase, is characterized by null preferences, and occurs as attention to the novel stimulus wanes but simultaneously increases to the familiar stimulus. Memories eventually become inaccessible during the fourth phase, during which null preferences would again be expected. The results of the present experiment are consistent with the first three phases of the model and provide evidence supporting this function for a younger age group, with stimuli from a different modality, and using a different methodology and dependent measure than previously examined by Bahrick and Pickens (1995). This shift in preference is also consistent with a model of forgetting in which "progressive loss of precision or completeness" (Estes, 1980, p. 67) of information occurs.

Although infants' stimulus preferences shifted from novel to null to familiar across time in both the present experiment and in that reported by Bahrick and Pickens (1995), the retention intervals at which specific preferences were observed differed across the two studies. For example, a preference for novelty was found at the 1-day retention interval in this study while Bahrick and Pickens (1995) found a null preference at this same interval. It seems reasonable to hypothesize that repeated familiarization with the nursery rhyme in the present study resulted in an elaborative representation of that stimulus that remained easily accessible for a longer time than a representation formed during a single brief exposure to a stimulus. However, given the procedural differences between the current research and that conducted by Bahrick and Pickens (1995), further research is needed to examine the relative contributions of a variety of factors to the four-phase function such as infant age, familiarization time, individual differences in memory functioning, and stimulus modality and complexity.

Infants in this study recognized the familiar rhyme even though the rhymes were recited by an unfamiliar voice at test. This result is consistent with previous findings that newborn and 1-month-old infants differentiated familiar and novel speech stimuli when spoken by unfamiliar voices at test (DeCasper & Spence, 1986; Ungerer et al., 1978). Infants also recognized the speech passage when tested in a novel context. Studies have shown that infants recognize previously experienced stimuli within novel testing contexts if the stimuli have been experienced in multiple training contexts (Amabile & Rovee-Collier, 1991; Rovee-Collier & Dufault, 1991). Infants in the present study were familiarized with their assigned nursery rhyme in multiple contexts such as during feeding, during diaper changes, while traveling in the car, and while being held by the mother. Mothers' logbook recordings revealed that familiarization sessions occurred in several contexts for most infants, $M = 3.7$, $SD = 1.49$. The present finding is consistent with previous results revealing that infants' dependence on contextual cues for memory retrieval can be eliminated by providing them with stimulus familiarization within multiple contexts.

The finding of a familiarity preference at a 3-day delay in the present experiment is consistent with the familiarity preference of newborns at 3- to 5-day retention intervals reported by DeCasper and Spence (1986). However, it is not possible to determine from these data whether similar behavioral preferences shown by newborns and 7-week-olds reflect retention of the same attributes or if these preferences reflect the same or different memory processes. Previous research has shown, for example, that 1- and 4-month-old human infants' preferences for infant-directed over adult-directed speech are influenced by different stimulus properties (Cooper, 1993; Fernald, 1985; Fernald & Kuhl, 1987). Four-month-olds' attention is directed by the wide-excursion frequency contours of infant-directed speech (Fernald & Kuhl, 1987), while 1-month-olds' preference for such speech relies on spectral composition of the signal in addition to frequency contour information (Cooper, 1993). Research examining the development of rat pups' olfactory memory has shown a dissociation of behavioral and neural correlates across the first 3 postnatal weeks, implying that different mechanisms may mediate memory at different ages (Sullivan & Wilson, 1995). Similar behaviors indicating olfactory memory were observed across the first 3 postnatal weeks, but changes in olfactory-bulb glomerular-layer responses were observed only during the 1st week. Further research with human infants is necessary for examining if these similar preferences found at different ages reflect similar memory processes, and also for identifying the acoustic attributes that are encoded and retained by infants at varying ages. The present results do, however, provide evidence that human infants as young as 5 to 7 weeks of age encode some acoustic attributes of naturally occurring speech into long-term memory and that the representation of these attributes influences infants' subsequent responsiveness to the speech stimulus.

Notes

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