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Discrimination of multisyllabic sequences by young infants

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DISCRIMINATION OF MULTISYLLABIC SEQUENCES BY YOUNG INFANTS

by

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Abstract

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By Roanne Gottlieb Karzon

Chairman: James D. Miller

Previous research has shown that infants of 1 to 4 months of age demonstrate discrimination of one- and two-syllable sequences which differ with respect to speech sound composition or suprasegmental parameters (e.g., intonation, stress, rhythm). It has been reported that the speech addressed to infants by caretakers has exaggerated suprasegmentals. Furthermore, recent studies indicate that, given a choice, infants prefer to listen to this exaggerated "infant-directed" style of speech rather than an "adult-directed" style of speech. Therefore, it was hypothesized that the exaggerated suprasegmentals of infant-directed speech may facilitate speech perception of infants in certain situations.

The specific goal of this research was to ascertain the effects of suprasegmental parameters (fundamental frequency, amplitude, and duration) on discrimination of multisyllabic sequences by 1- to 4-month-old infants. Specifically, the experiments were designed to answer two primary questions. First, do young infants demonstrate discrimination of multisyllabic sequences (e.g., /marana/ versus /malana/) which differ by only one speech sound? Second, do suprasegmental parameters influence the performance of infants? A high-amplitude sucking procedure with synthetic speech was used to assess discrimination performance.

Results of this study indicated that young infants demonstrated

discrimination of the three-syllable sequences /marana/ versus /malana/ when intonation, relative amplitude, and duration typical of infant-directed speech emphasized the middle syllable. The infants failed to demonstrate discrimination of these sequences in several other conditions tested: 1) if all three syllables in each sequence had equivalent values for duration and loudness, and pitch varied slightly; 2) if the syllable of contrast was emphasized by pitch alone; 3) if the syllable of contrast was emphasized with suprasegmentals appropriate to conversational speech of adults; and 4) if infant-directed suprasegmentals emphasized the initial syllable rather than the syllable of contrast.

This pattern of results suggests that the exaggerated suprasegmentals of infant-directed speech can function as a "perceptual catalyst," facilitating discrimination by focusing the infant's attention on the distinctive syllable of multisyllabic sequences.

TABLE OF CONTENTS

Page

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LIST OF TABLES

LIST OF FIGURES

Chapter 1

STATEMENT OF THE PROBLEM

Infants have demonstrated that they can discriminate both the segmental aspects of speech (i.e., consonants, vowels, syllables) and the suprasegmental characteristics of speech (i.e., intonation, stress, and rhythm). Many researchers have assessed the ability of infants to discriminate segmental aspects of speech in the context of single syllables. Several studies have examined discrimination performance of infants with multisyllabic sound sequences. Only a few studies have focused on the discrimination of speech segments which differ with respect to suprasegmental characteristics.

Evidence that suprasegmental parameters may play an important role in perception of speech by infants may be gleaned from two complementary areas of infant research. First, descriptive studies of infant-directed speech[1] indicate a tendency of speakers to exaggerate suprasegmental characteristics when addressing infants and young children. Second, studies of the listening preferences of infants suggest that they prefer infant-directed speech with exaggerated characteristics to adult-directed speech.

The goal of this research was to ascertain the effects suprasegmental parameters have on discrimination of multisyllabic sequences

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[1] "Infant-directed speech" (synonymously "baby talk" and "motherese") refers to the special characteristics of speech and language typically employed by people when addressing infants and young children.

by young infants (i.e., 1 to 4 months of age). Thus, the experiments were designed to answer two primary questions. First, can young infants demonstrate discrimination of multisyllabic sequences which differ by only one speech sound? Second, do suprasegmental parameters (i.e., fundamental frequency, intensity, and duration) influence the performance of the infants?

Chapter 2

REVIEW OF PRIOR RESEARCH

Studies of Infant-directed Speech

Many researchers have reported that adults and older children modify their speech when addressing infants and young children. Observational studies have been performed in a wide variety of linguistic and cultural settings as shown in Table 1.[2] Numerous features of infant-directed speech have been identified[3] and may be classified according to the categories set forth by Kaye (1980):

> 1) prosodic features--higher pitch, greater range of frequencies, more varied intonation (Sachs, 1977; Garnica, 1977); 2) lexical features--special forms like "potty" and "nana" (Ferguson, 1964); 3) complexity features--shorter utterances, fewer embedded clauses, fewer verb auxiliaries, etc. (Snow, 1977a; Furrow, Nelson and Benedict, 1979); 4) redundancy features--more immediate repetition and more repetition of the same words or phrases over a period of time (Snow, 1972); and 5) content features--restriction to topics in the child's world (Snow, 1977b). (p. 490)
>
> [emphasis added]

Prosodic phenomena are most important with respect to the present study. A list of frequently occurring prosodic modifications observed in speech to infants and young children is shown in Table 2.

The apparent universality of many infant-directed features led

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[2]For a review of these studies see Depaulo and Bonvillian (1978), Andersen (1977), Blount (1977) and Ferguson (1977).

[3]Ferguson (1964) identified a total of 60 linguistic items of infant-directed speech in the course of studying several language cultures. Brown (1977) spoke of the 100+ features that constitute English "baby talk".

Table 1.

Languages and Cultures Studied for Descriptions of Speech Addressed to Infants and/or Young Children

Language/Dialect	Author (year)
Arabic/Syrian	Ferguson (1956)
East African Bantu	Harkness (1977)
Berber/Central Morocco	Bynon (1977; 1968, cited in Andersen, 1977)
Cocopa	Crawford (1970)
Comanche	Casagrande (1948)
Dutch	Snow et al. (1976)
English/Australia	Cross (1977, 1979)
English/Great Britain	Read (1946, cited in Ferguson, 1977)
French	Rondal (1980)
German	Fernald (1978)
Gilyak/ S.E. Sakhalin	Austerlitz (1956)
Greek/ Athens, Cypriot, Acarnanian	Drachman (1973, cited in Ferguson, 1977)
Hidatsa	Voegelin & Robinett (1954)
Japanese/Fukuoka	Fischer (1970)
Japanese/Tokyo	Chew (1969, cited in Ferguson, 1977)
Kannada/Havyaka	Bhat (1967)
Latvian	Ruke-Dravina (1977)
Luo	Blount (1972)
Maltese	Cassar-Pullicino (1957)
Marathi/Standard	Kelkar (1964)
Pomo	Oswalt (1976)
Romanian	Avram (1967)
Samoan	Blount (1972, 1977)
Spanish/Guatemala	Harkness (1976)
Spanish/Mexcico, Chile, Peru, Argentina, Texas	Blount & Padgug (1976)
Spanish/Mexico, Chile	Ferguson (1964)

English /American

Read (1946, cited in Ferguson, 1977); Anderson & Johnston (1973); Gleason (1973, 1975, 1977); Broen (1972); Blount & Padgug (1976); Ferguson (1964); Phillips (1973); Sachs et al. (1976); Shatz & Gelman (1973); Weeks (1971); Furrow et al. (1979); Drach (1969); Wilkinson et al. (1981)

Table 2.

Prosodic Modifications Observed in Speech Addressed to Infants and/or Young Children

Feature	Researchers (year)
Fundamental frequency is significantly higher.	Drach, 1969; Sachs et al., 1976 Blount & Padgug, 1976; Remick, 1976; Garnica, 1977; Stern, 1977; Ruke-Dravina, 1977; Fernald, 1978.
Frequency range is larger and is extended significantly at the upper end. Thus, intonation is more varied.	Drach, 1969; Sachs et al. 1976; Blount & Padgug, 1976; Remick, 1976; Stern, 1977; Fernald, 1978.
Rising terminal pitch is observed in significantly more sentences.	Garnica, 1977.
Unidirectional pitch-glide contours or "glissando-like" contours occur significantly more often.	Stern, 1977; Fernald, 1978.
Repeated pitch contours (i.e., frequent successive repetition of similar pitch contours) have been noted.	Fernald, 1978.
Simple harmonic intervals are used frequently when there is an abrupt pitch change. Infant-directed speech has a sing-song or melodic quality.	Fernald, 1978.
Exaggerated temporal rhythmicity has been found as well as more marked stress patterns to increase emphasis on certain syllables, words or phrases. The rhythmic patterns may contribute to the sing-song quality.	Garnica, 1977; Stern, 1977.
Slower rate of speech has been observed. There are longer pauses between utterances and pauses which coincide with phrase boundaries are typical.	Drach, 1969; Broen, 1972; Sachs et al., 1976; Ruke-Dravina, 1977; Stern, 1977; Fernald, 1978; Cross, 1977; Blount and Padgug, 1976.
Marked intensity shifts including occasional whispering.	Garnica, 1977; Fernald, 1978; Blount and Padgug, 1976; Stern, 1977.

to speculation that these special characteristics may play a role in language, communication, and/or social development (Blount, 1972; Ferguson, 1977; Fernald, 1982). Hypotheses emanating from the descriptive studies of infant-directed speech with respect to prosodic modifications include the following:

1) Intonation, stress and rhythm patterns highlight important distinctions within the sound sequence (Garnica, 1977; Fernald, 1982). In particular, exaggerated intonation may increase "the potential for acoustic contrast among individual linguistic elements within the utterance ...." (Fernald, 1978, p. 9).

2) Suprasegmental variation serves to attain and/or maintain infant attention (Sachs et al., 1976; Sachs, 1977; Fernald, 1978; Blount and Padgug, 1976; Garnica, 1977; Snow, 1977b; Chapman, 1981).

3) Prosodic patterning serves to segment or organize the speech stream for the infant (Drach, 1969; Kaplan and Kaplan, 1971; Garnica, 1977) In Fernald's words, it "helps the infant segment the speech stream into discrete linguistic units" (Fernald, 1978, p. 9).

4) The special style of speech establishes the affectational bond and facilitates the earliest verbal communication between infant and caregiver (Sachs, 1977; Stern, 1977).

5) Highly inflected speech may aid infants in selectively attending to one voice among many more readily. For example, higher pitch may aid children in identifying speech addressed to them (Ferguson, 1977; Garnica, 1977; Fernald, 1978; Chapman, 1981).

Most of the studies have concentrated on speech addressed to children between the ages of 1 and 4 years. A few studies have reported on the speech addressed to infants less than one year of age. Blount (1972, 1977) noted that in the Luo culture caretakers modified their speech to "prelinguistic" children and that the number and frequency of special modifications decreased considerably at about 12 to 14 months of age. Kaye (1980) observed the speech addressed to young infants of 6, 13, and 26 weeks of age. He found that speech to younger infants was more repetitive and more abbreviated than that to infants older than 12 months. Snow (1977b) investigated infant-directed speech with infants of 3 to 18 months of age. She found that although the 3-month-old infants were considerably less responsive as conversational partners, mothers' speech to the 3-month-old infants contained the same types of modifications as that to the 18-month-old infants (Snow, 1977b). Snow also reported the findings of Bingham (1971), who found that "prelinguistic children elicit simplified speech from adults who believe that the children are cognitively advanced and can understand a great deal, but not from adults who do not believe this" (Snow, 1977a, p. 37). Blount (1977) provided anecdotal evidence of special modifications to young infants:

> ... In a study of caretaker speech in Austin, Texas, two parents used greater ranges in pitch and volume, more frequent falsetto and more nonsense items in their speech to their 3-month-old infant than to their 16-month-old toddler.(p.306)

To date, prosodic phenomena in speech addressed to infants have not been studied in a developmental framework for infants from birth to four years and there have been very few studies which have systematically tested the hypotheses concerning the role of the modifications in infant-directed speech. Investigating the overall effect of infant-directed features, Snow (1976) compared responses of 2-year-old and 10-year-old children to taped speech which had infant-directed characteristics with their responses to tapes of normal adult speech. The content was the same in both samples. Snow (1976) found that "children are more attentive to simplified, repetitive speech and that they tend to be able to follow instructions given in that speech style better " (p. 264). Snow (1976) interpreted these findings as follows:

> I think all these experiments taken together show that children are in some sense, demanding a certain speech style from the adult. By becoming inattentive to and noncomprehending of more complex speech styles, they constantly cue the adult speaker as to what level of complexity and redundancy is necessary. In the process, children also provide themselves with primary linguistic data which make the structure and the rules of the language maximally transparent. It is tempting to think that they do this because they need precisely this kind of primary linguistic data in order to be able to acquire language. (p. 264)

Fernald and Kuhl (1982) investigated the effect of highly prosodic infant-directed speech on the discrimination performance of 6-month olds using a head-turn procedure. In this study infants were asked to discriminate a phonetic contrast embedded within a multisyllabic sequence. The stimuli /gala<u>sa</u>laga/ and /gala<u>ta</u>laga/ were presented for discrimination in two conditions: 1) with adult-directed intonation, and 2) with infant-directed intonation. Infants demonstrated discrimination of the stimuli in both conditions; however, performance was slightly better in the infant-directed condition.

In summary, among the numerous features of infant-directed speech are several modifications of the suprasegmental aspects of speech. Speech addressed to infants has exaggerated intonation, stress and rhythmic patterns. Guided by descriptive studies, researchers have speculated on the facilitative role infant-directed suprasegmental parameters may play in communication and language acquisition. Very few experiments have been performed to test the hypothesis that infant-directed speech facilitates the processing of speech.

Listening Preference Studies

The goal of most listening-preference studies has been to learn about attention in general. Because stimuli have not been systematically controlled with respect to prosodic cues, results often provide only marginal support for the hypothesis that suprasegmental variation serves to attain and/or maintain infant attention.

Friedlander (1968) examined the effects of speaker identity, voice inflection, vocabulary and message redundancy on infants' listening preferences (3 subjects, 11 to 15 months of age). He used a behavior analysis technique with two automated toys fitted to each infant's playpen (infants could not reach both toys simultaneously). Playing with a toy turned on a corresponding channel of a tape loop system. Thus, the relative "on time" for each stimulus of the pair indexed listening preference. The babies clearly preferred their mothers' voice with "bright inflection" to Bach organ music. Friedlander (1968) observed that a two-stage response pattern occurred for the stranger's voice with "bright inflection" versus the mother's voice with "flat inflection" for the oldest infant (15 months of age). At first, this infant preferred the stranger's voice, but after a period of mixed responses, preference for the mother's voice emerged. Friedlander (1968) inferred that the older infant was eventually able to "conserve" essential properties of the mother's vocal identity, while the younger infants could not make the conservation. In another condition, a

12-month-old-baby, who initially preferred the mother's voice with "bright inflection," soon switched and showed a clear preference for the mother's voice with "flat intonation".

Friedlander (1968) explained how these types of responses facilitate language acquisition:

> A 'listening appetite' for the partially familiar and partially unfamiliar would have the effect of continually exposing the baby to new vocal models over a continually expanding range. (p.454)

Unfortunately, Friedlander (1968) does not describe his "bright" versus "monotonous" speech in acoustical terms. It is not clear whether the "bright intonation" was due to variation in fundamental frequency, duration, intensity or some combination of these features.

Friedlander's data from experiments on redundancy was in accord with the notion of "listening appetite". An 11-month-old infant shifted preference from a highly redundant message to a less redundant message (Friedlander, 1968). This shift in preference was observed in two separate experiments. In the first, the infant selected between a message which repeated every 20 seconds and a message which repeated every 240 seconds; in the second, the infant chose between a message repeated every 40 or every 120 seconds. In a later experiment 11 infants of 9 to 18 months of age were tested. Friedlander and Wisdom (cited in Friedlander, 1970) found that 7 infants eventually showed significant preference for a high information, low redundancy message. Five of these 7 infants demonstrated a robust crossover effect.

Examining preferences in younger infants of 3, 6 and 9 months, Turnure (1969; cited in Northern and Downs, 1974) found that by the age of 3 months a baby is more attentive to a tape recording of his mother's voice than to a tape of a stranger's voice. Whether the mother and/or stranger tapes were recorded with adult-directed or infant-directed speech styles is not reported. A baby prefers his mother's voice even when it is distorted by filtering. Based on behavioral observations, Turnure (1969) reported differences in the response mode of the infants as a function of age. "The nine-month olds tended to be quieter to the natural mother's voice and progressively less attentive to the distortions" (Northern and Downs, 1974 p.66).

Jones-Molfese (1977) used an operant-response method to investigate and rank order preferences among the following natural speech stimuli: 1) inflected speech spoken at a mean rate of 88 words per minute; 2) monotonal speech spoken at a mean rate of 55 words per minute; and 3) inflected speech with scrambled word order spoken at a mean rate of 62 words per minute. Although infants over a wide age range (3 to 14 months) were tested, there was no significant relationship between age and stimulus preference. The infants showed a preference for the inflected and monotonal speech over the speech with scrambled word order. However, since the stimuli were constructed such that the less inflected speech had a slower rate and the more inflected speech had a faster rate, one cannot ascertain the extent to which the differences in preference were attributable to either variable. Extrapolating from studies of infant-directed speech findings, one would expect infants to prefer slower, more inflected speech.

Kinney and Kagan (1976) investigated infant attending behavior with two classes of stimuli, verbal and musical, using a habituation-dishabituation paradigm with cardiac deceleration as the primary response measure. The degree of similarity between the familiarization and dishabituating stimuli was varied to create increasing degrees of stimulus-schema[4] discrepancy. The verbal stimuli were four-syllable utterances. A difference in intonation marked the slight discrepancy stimuli. Both intonation and the two middle syllables were changed in the moderate discrepancy stimuli. The extreme discrepancy stimuli differed with respect to intonation and all four syllables. The patterns of cardiac deceleration in the 7 1/2-month-old subjects supported a "discrepancy hypothesis":

> events that represent a moderate degree of discrepancy from the child's schemata will maintain longer attentional involvement than those that are familiar or extremely discrepant. (Kinney and Kagan, 1976, p.155)

Kinney and Kagan (1976) also found more fretting to the verbal than to the musical stimuli. They offered the following interpretation of this finding:

> [it may be] due to the fact that the fretfulness reflected apprehension akin to stranger anxiety.... It is tempting to speculate that the greater fretting to the verbal stimuli may reflect the fact that infants' schemata for voices and speech are more salient and better articulated than those for musical melodies. (p. 163)

Using natural speech, DeCasper and Fifer (1980) investigated the listening preferences of newborns (less than three days of age). Presentation of different samples of recorded speech were made contingent upon the pattern of nonnutritive sucking. The stimuli for each subject consisted of a sample of speech from his own mother and from the mother of another newborn. DeCasper and Fifer (1980) found that the "infants learned how to produce their mother's voice and produced

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[4]"Schemata" are defined as "persistent deep rooted, well-organized classifications of situations and of kinds of behavior appropriate in these situations" (Ruch, 1958, p. 604).

it more often than the other voice" (p. 1174).

Fernald (1981) speaks directly to the question of whether or not infants prefer adult-directed or infant-directed speech. In her experiment tape recordings of adult women were made under two conditions: 1) talking to their 4-month-old infants, and 2) talking to an adult interviewer. A second group of 4-month-old infants served as subjects in the preference experiment. A head-turn response to one side produced a eight-second sample of infant-directed speech and a response to the opposite side produced a eight-second sample of adult-directed speech. Fernald (1981) found a clear preference for the infant-directed rather than the adult-directed speech.

Using a similar procedure in a follow-up study, Fernald and Kuhl (1981; Fernald 1982) tested the hypothesis that a preference for expanded pitch contours could account for the demonstrated preference for "motherese". A pure tone was modulated in frequency; amplitude was held constant. Values for the frequency contour and duration of the pure tone signals matched those of the speech samples used in Fernald (1981). The authors found that the infants preferred the infant-directed contours. Indeed, "...infants showed an even stronger preference for the isolated pitch contours in this study than was shown for the natural 'motherese' speech samples in the original study" (Fernald and Kuhl, 1981, p.2). In two later experiments, Fernald (1982) presented contours derived from the amplitude and duration characteristics of adult-directed and infant-directed speech. Since the infants did not show a preference for the infant-directed contours in these later experiments, Fernald (1982) concluded that preference for infant-directed speech is more strongly influenced by the fundamental frequency charcteristics than by the amplitude and duration characteristics of infant-directed speech.

In summary, the early studies of listening preference were designed to discover the types of auditory stimuli that capture and maintain the attention of infants. The speech stimuli were typically samples of natural speech with durations of several seconds. The stimuli were usually described in general terms; therefore, it is difficult to interpret the results with respect to the influence of specific infant-directed features. The later studies have shown that infants prefer the voice of their mothers rather than the voice of a stranger (DeCasper and Fifer, 1980) and that infants prefer infant-directed rather than adult-directed speech (Fernald, 1981). This preference of infants for infant-directed speech appears to be due, in part, to exaggerated intonation characteristics.

These studies may also reflect the discrimination abilities of infants. If infants prefer one stimulus to another, it may be inferred that they can discriminate the stimuli. Studies which focus more directly on the discrimination abilities of infants are reviewed in the following section.

Studies of Speech Discrimination

Over the past 14 years numerous studies have been performed to investigate the ability of infants to discriminate speech and non-speech sounds in a wide variety of conditions. The three areas which are important with respect to the present study are 1) studies of developmental phonology, 2) studies of suprasegmental characteristics, and 3) studies of discrimination with multisyllabic sequences.

Before reporting the results of research on speech discrimination with infants for these three areas, it is important to describe briefly the three techniques for testing which have been successfully employed. The high-amplitude-sucking paradigm will be fully discussed in Chapter 3. Descriptions of the heart-rate and head-turn techniques are given below.

Heart-Rate

Moffitt (1968, 1971) performed one of the first studies of discrimination with young infants (5 to 6 months of age) using synthetic speech and the heart-rate procedure. The heart-rate procedure is a habituation-dishabituation paradigm. Infants initially respond to an auditory stimulus of moderate intensity with an orienting response.[5] One measurable component of the orienting response is cardiac deceleration.

A baseline measure of heart-rate is made during a period of quiet. Then infants are exposed to auditory stimuli for a fixed number of presentations and the orienting response is indexed by cardiac deceleration. After repeated presentation of the same stimulus, the orienting response habituates. At this point in the procedure, a different or novel sound is introduced for infants in the experimental group. Infants in the control group continue to hear the same stimulus throughout the test period. Since the orienting response usually takes

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[5]"An organism presented with an unexpected stimulus usually exhibits what Ivan Pavlov called an orientation reflex, which includes increased electrical activity in the brain, a reduction of blood flow to the extremities, changes in the electrical resistance of the skin, a rise in the level of adrenal-steroid hormones in the blood and some overt motor activity of the body. If the stimulus is repeated frequently, these reactions eventually disappear; the organism is then said to be habituated to the stimulus." (Levine, 1971, p. 196)

several seconds to complete its cycle, a 20- to 30-second intertrial interval is usually employed (Trehub et al., 1981). Discrimination of the two auditory stimuli is inferred if the orienting response of the experimental group recovers significantly relative to the control group.

A modification of the heart-rate technique, the "no-intertrial-interval paradigm", involves the presentation of several repetitions of the familiarization stimulus followed by several repetitions of the novel stimulus. In contrast to the original heart-rate procedure, in this modified procedure a short interstimulus interval is employed. The modified heart-rate procedure has proved successful in several studies (e.g., Miller et al., 1977; Till, 1976; and Leavitt et al., 1976).

Although heart-rate measures have been used with newborns, they are most reliable with infants older than 2 months of age (Morse, 1974). Note that interpretation of results depends on collection and analysis of group data. For in-depth reviews of the heart-rate paradigm and its use in studies of auditory perception in infants see Trehub et al. (1981) and Morse (1974, 1979).

Head-Turn

The head-turn technique was developed by Wilson, Moore and Thompson (1976) for assessing audiometric thresholds (Kuhl, 1979). Modifications by Eilers et al. (1977) adapted the technique for studies of speech discrimination in infants.

In the head-turn procedure, the infant is conditioned to make a headturn when a change is heard in the auditory stimulus. A background sound (e.g., sa-sa-sa-sa) is presented repeatedly through a loudspeaker located to the front and side of the infant. After several seconds of the background stimulus, a new sound is presented (e.g., za-za-za-za) and repeated several times. The duration of the inter-sound intervals is usually about one second (Trehub et al., 1981). If the infant turns his or her head toward the loudspeaker within a few seconds of the change in stimuli, an animated visual reinforcer located near the loudspeaker lights up for 3 or 4 seconds. Control trials consist of repetitions of the background sound throughout the trial period and a head turn is considered an incorrect response. Discrimination between the background sound and the test stimulus is inferred if significantly more head turns occur on change trials and few incorrect responses are made during control trials.

The head-turn technique has been used successfully with infants as young as 5-1/2 months of age (Kuhl 1979) and as old as 18 months of age (Eilers et al., 1977). However, the highest rate of success (with respect to conditioning and cooperation) is reported for infants of 5-1/2 to 10 months of age (Kuhl, 1979). In contrast to the heart-rate and sucking techniques, individual data collected with head-turn may be interpreted. Further discussion of this technique may be found in Trehub et al. (1981), Kuhl (1979) and Eilers et al. (1977).

Developmental Phonology

Writing in 1975, Eimas stated that

> in summarizing our research to date, we are able to conclude that very young infants are certainly sensitive to the segmental sound units of speech. (Eimas, 1975a, p.224)

The strong form of this hypothesis, i.e., that infants are innately predisposed to discriminate all possible speech sounds necessary for all spoken languages, has been challenged by the findings of several studies. Contradictory evidence has been generated primarily by developmental studies of the perception of stop consonants and fricatives.

Using heart-rate as the response measure, McCaffrey (1971) investigated discrimination of several speech sounds spoken by an adult female: *papa* versus *tata*, *kaka*, *sasa*, and *nana*; *tata* versus *papa*, *kaka*, *sasa*, and *nana*; and *kaka* versus *papa*, *tata*, *sasa*, and *nana*. The age of the subjects ranged from 11 to 28-1/2 weeks. Results showed that speech sound contrasts differentiated by the feature coronal[6] were discriminated more often and at an earlier age than contrasts differentiated by other features.

Stop consonants have been the focus of several studies. Infants of 1 to 4 months of age have demonstrated discrimination of stop consonants that differ with respect to presence or absence of voicing: /*b*/ versus /*p*/ (Eimas et al., 1971; Trehub and Rabinovitch, 1972); and /*d*/ versus /*t*/ (Trehub and Rabinovitch, 1972; Eimas 1975a; Eilers, 1977). Infants also appear sensitive to speech sounds which differ with respect to place of articulation: /*b*/ versus /*g*/ (Moffit, 1971); /*d*/ versus /*g*/ (Eimas, 1974; Jusczyk, 1977; Williams and Golenski, 1978; Williams and Bush, 1978); and /*b*/ versus /*d*/ (Eimas, 1974; Jusczyk et al., 1979).

Eilers and her colleagues have investigated the perception of natural fricatives (/*s*, *v*, *ʃ*, *z*, *f*, *θ*/) and stop consonants (/*t*,*d*/)

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[6] "Coronal sounds are made with the blade of the tongue; thus coronal *t* is opposed to noncoronal *p* and *k*." (Schane, 1973, p. 15) Therefore, in the McCaffrey (1971) study the coronal sounds were *t*, *s*, and *n* and the non-coronal sounds were *p* and *k*.

with 1- to 4-month-old infants using sucking procedures, and with 6- to 14-month-old infants using a head-turn technique. Developmental trends in discrimination performance were found for several of the fricative sounds (Eilers et al., 1977). For example, Eilers and Minifie (1975) found that 1- to 4-month old infants demonstrated discrimination of /sa/ versus /va/ and /sa/ versus /ʃa/, but not for /sa/ versus /za/. Eilers et al. (1977) tested two groups of older infants (6- to 8-month old infants and 12- to 14-month-old infants) and found evidence of discrimination for all three pairs of speech sounds. Based on results of a variety of stimulus pairings, Eilers et al. (1977) suggested that for final position stops and fricatives, acquisition may proceed in the following order:

> (1) [as] vs [a:z] and [at] vs [a:d] (where both voicing and vowel duration differences are present).
> (2) [a:s] vs [a:z] (here vowel durations are relatively equalized, but the long periods of voicing during final fricatives provide a basis for the discrimination).
> (3) [a:t] vs [a:d] (where the stimuli differ in voicing only during the relatively short duration of the final stop).
> (4) [a:t] vs [at] (where stimuli differ only in vowel duration).
> (Eilers et al., 1977, p. 778)

Although the details of specific experiments are not in total agreement, the results do suggest a developmental trend in the ability of infants to discriminate both fricatives and stop consonants. In addition to variations in testing technique, differences in results may be due to stimulus parameters such as natural versus synthetic speech, the position of the consonants within the syllable, and the interaction between the consonant and the vowels selected as context for the consonant contrast.

With respect to the nasals, liquids, and semivowels (/m, n, l, r, j, w/), results with stimuli of one and/or two syllables suggest that infants within the age range of 1 to 6 months demonstrate discrimination of the following pairs: /m/ versus /n/ (Hillenbrand, 1980); /j/ versus /w/ (Jusczyk et al., 1978); and /l/ versus /r/ (Eimas, 1975b). The sounds selected for the present study were selected from this group.

To date several vowel contrasts have been investigated. Results indicate that infants as young as 1 to 4 months of age discriminate the following vowels: /a/ versus /i/ (Trehub, 1973; Kuhl and Miller, 1975; Kuhl, 1976); /a/ versus /ɔ/ (Kuhl, 1977); /i/ versus /I/ (Swoboda et al., 1976); and /i/ versus /u/ (Trehub, 1973). Vowels in context can also be discriminated: e.g., /ta/ versus /ti/ and /pa/ versus /pi/ (Trehub, 1973).

A study by Trehub (1976) supports the "detuning" hypothesis, i.e., the hypothesis that linguistic experience with one language may contribute, over a period of time, to a lack of sensitivity for phonemic contrasts foreign to that language. Using a high-amplitude-sucking procedure, Trehub (1976) found that 1- to 4-month-old infants could discriminate /ř/ versus /ʒ/ (a contrast used in Czech). She excluded infants from families where Czech or other Eastern European languages were spoken. Trehub (1976) also reported that given similar stimulus presentation conditions, adult listeners whose native language was English frequently confused this pair.

In summary, infants as young as 1 to 4 months of age demonstrate discrimination of a wide variety of speech sounds. However, discrimination of certain sounds appears to follow a developmental progression. The role of linguistic experience has yet to be fully defined. In most of the studies it appears that linguistic experience serves to make the infants more sensitive to contrasts between certain speech sounds. The case in which infants demonstrated discrimination of sounds which adults readily confused suggests that linguistic experience may also modify perception by making it less sensitive.

Studies of Suprasegmental Characteristics

Several researchers have examined the ability of young infants to discriminate speech sounds on the basis of suprasegmental characteristics. If as hypothesized above, the exaggerated intonation, duration, and loudness of infant-directed speech facilitate processing of speech by infants, then infants must be able to perceive changes in these suprasegmental parameters.

Kaplan (1970) used a habituation-dishabituation paradigm with heart rate and behavioral observation as the response measures to assess discrimination of intonation and stress patterns by infants. A naturally spoken utterance, "see the cat," served as the stimulus. Two sets of terminal intonation contours were tested: 1) falling versus rising with stress; and 2) falling versus rising without stress. In the first condition 8-month-old infants demonstrated discrimination of terminal intonation contour but the 4-month-old infants failed to provide evidence of discrimination. Based on these results, Kaplan (1970) suggests that the ability to discriminate between simple intonation patterns with concomitant stress that are characteristic of American-English develops between 4 and 8 months of age. Responses to the other stimulus condition, in which terminal contour differed (rising versus falling) without stress, indicated that neither 4- nor

8-month olds discriminated these stimuli. Kaplan (1970) suggests that concomitant stress and pitch patterns, which characterize terminal contour in American-English speech, may be important for detection of changes in terminal intonation contours by infants.

The findings of Morse (1972) pointed toward a different conclusion. Morse also used the habituation-dishabituation paradigm, but measured changes in high-amplitude sucking rather than heart rate or behavior. The stimuli were generated from the parallel resonance synthesizer at Haskins Laboratories. In an intonation experiment the stimuli /<u>ba-</u>/ and /<u>ba+</u>/ were designed to differ only in the terminal portion of their fundamental-frequency contour. For the stimuli /<u>ba+</u>/ the fundamental frequency rose from 120 to 194 Hz, whereas for /<u>ba-</u>/ the fundamental frequency dropped from 120 to 70 Hz. The fundamental frequency changes for both stimuli occurred during the last 150 msec. of the speech stimulus and were concomitant with a decrease in overall amplitude. Results indicated that by 40 to 54 days of age, infants demonstrated discrimination of this acoustic cue for intonational differences.

What could be responsible for the disparate results of Kaplan (1970) and Morse (1972)? Perhaps stimulus differences were significant. Morse's (1972) synthetic one-syllable stimuli were of short duration and contained less phonetic variation than the stimuli used by Kaplan (1970). Thus, in a sense, Morse's (1972) stimuli were "less complex" and perhaps this made the suprasegmental changes more apparent to the infants. Also the conjugate sucking paradigm used by Morse (1972) may be a more sensitive response measure than the heart-rate procedure used by Kaplan (1970). Perhaps the more interactive participation of the infant in the sucking paradigm contributes to demonstration of discrimination ability.

Spring and Dale (1977) explored the ability of young infants to discriminate syllabic stress in disyllables (/<u>bába</u>/, /<u>babá</u>/). Discrimination by 4- to 17-week-old infants was assessed using a high-amplitude-sucking paradigm. The acoustic parameters of the synthetic stimuli relevant to the study are shown Table 3. Results of the first experiment indicated that given changes in the three primary physical correlates of syllabic stress (i.e., fundamental frequency, intensity, and duration), the infants could discriminate the stimuli. Furthermore, in the second experiment, the post-shift rates of recovery demonstrated that young infants are able to discriminate disyllables with duration as the only cue for stress. The results of the second experiment seem even more remarkable if it is noted that the duration difference between pre- and post-shift stiimuli was less than 30 msec. (see Table 3).

Jusczyk and Thompson (1978) also investigated discrimination of syllabic stress; they used the synthetic disyllables /<u>dága</u>/ and /<u>dagá</u>/ with the high-amplitude-sucking procedure. The stressed syllables had durations of 364 msec. and fundamental frequency contours which peaked at 130 Hz. The unstressed syllables had durations of 208 msec. and fundamental frequency contours which peaked at 117 Hz. In addition, the stressed syllables were marked by a 5 dB increase in amplitude relative to the unstressed syllables. Jusczyk and Thompson (1978) found that 2-month-old infants responded to the change in the stress patterns of the disyllabic sequences presented.

Results of a series of experiments by Kuhl and her associates

Table 3.

Acoustic Parameters of the Disyllables used by Spring and Dale (1977)

	Disyllable					
	First Syllable			Second Syllable		
	FØ Peak	Intensity Peak	Duration	FØ Peak	Intensity Peak	Duration
Experiment						
Experiment 1						
/bába/	125 Hz	56 dB	100 msec.	108 Hz	54 dB	107 msec.
/babá/	110 Hz	52 dB	57 msec.	118 Hz	54 dB	164 msec.
Experiment 2						
/babá/	114 Hz	56 dB	114 msec.	130 Hz	56 dB	143 msec.
/babá/ (duration equalized)	114 Hz	56 dB	114 msec.	130 Hz	56 dB	120 msec.

(copied from Spring and Dale, 1977, p. 227) suggest that several factors determine whether infants respond to differences in the fundamental-frequency contour of synthetic vowels. Kuhl and Miller (1975) studied discrimination of the vowel /a/ versus /i/. They tested 1- to 4-month-old infants using the high-amplitude-sucking technique and found that

> although infants detect a change in the pitch contour of a vowel when all other dimensions are held constant, they do not respond to a pitch contour change when the vowel color is randomly varied throughout the experiment. (Kuhl, 1976, p. 274)

In this experiment Kuhl and Miller (1975) contrasted monotone pitch contours with rise-fall pitch contours. Kuhl (1976) interpreted the findings as follows:

> The fact that infants responded for a significantly longer period of time before habituating when the vowel was constantly changing than when the pitch contour was constantly changing supports the idea that an infant's attention is more arrested by a change in vowel color than by a change in the pitch contour of a single vowel. (p. 276)

In a later study with older infants (6 months of age) using the head-turn procedure, Kuhl (1977) contrasted a rising pitch contour with a rise-fall pitch contour. The vowel contrasts were /a/ versus /ɔ/. The values for the pitch contours specified in the 1977 study were as shown in Table 4. The fundamental frequency values employed fall within the range of normal adult prosodic variation. Kuhl (1977) found that

> while infants find it relatively easy to differentiate this group of sounds on the basis of vowel color, they have difficulty grouping the stimuli according to pitch contour. That is, while infants can easily be trained in the initial training sessions to respond to a change in the pitch of a single vowel, they do not readily generalize to other tokens in which the pitch contour rises or falls. In other words, using these tokens, it is easier for infants to abstract a similarity in vowel color than it is to abstract a similarity in pitch contour. (p. 3)

The key phrase here may be "using these tokens." The reported lack of

Table 4.

Target Values of Fundamental Frequency used by Kuhl (1977)

	Talker		
Contour	Male	Female	Child
Rise-fall	112-132-92 Hz	189-223-155 Hz	224-264-184 Hz
Rise	112-132 Hz	189-223 Hz	224-264 Hz

from Kuhl (1977) [paper presented to the Acoustical Society of America June, 1977.]

response to a change in pitch contour in the younger infants and the poor response of the older infants may be due in part to stimulus characteristics. As previously discussed, speech addressed to infants by their caretakers contains exaggerated suprasegmental patterns relative to the suprasegmental patterns of normal adult speech. Thus, in these experiments the relatively small differences among the intonation contours may not have been salient for the young infants. Another factor may be the length of utterance. Perhaps the importance of pitch contour increases with longer, multisyllabic sequences (Fernald, 1982).

In summary, the published studies suggest that young infants are capable of discriminating stimuli on the basis of changes in suprasegmental characteristics. It is clear from the work of Kaplan (1970) and Kuhl and Miller (1975) that there are limits to this ability. Research is needed to determine what factors prevent infants from discriminating two stimuli which differ according to suprasegmental parameters. The minimal differences in frequency, intensity, and duration necessary to provide a discriminable cue have not yet been determined.

Studies of Multisyllabic Sequences

In a number of studies, young infants of 1 to 4 months of age have also demonstrated discrimination of two-syllable sequences which differ by one speech sound. Trehub (1973) found evidence of discrimination of natural tokens of /aba/ versus /apa/. Jusczyk and his colleagues assessed performance and obtained positive results for the following stimulus pairs: /daba/ versus /daga/, and /bada/ versus /gada/ (Jusczyk and Thompson, 1978); /dawa/ versus /daja/, and /wada/

versus /jada/ (Jusczyk et al., 1978).

To date, young infants of 1 to 4 months of age have not demonstrated discrimination of three-syllable sequences which differ by one speech sound. Using the high-amplitude sucking technique, Trehub (1973) presented naturally spoken versions of /atapa/ versus /ataba/. She did not find significant recovery of the sucking response with these stimuli. It is difficult to reach a conclusion about the ability of young infants to discriminate three-syllable sequences on the basis of a single study. There are several factors which could influence performance. First, the high-amplitude sucking technique may not be sensitive enough. Infants may be capable of discriminating the sequences, but the change in the speech sounds under study may not be sufficiently novel to cause recovery of the sucking response. Second, the magnitude of the phonemic difference may play a role. For example, /b/ verus /p/ (tested by Trehub, 1973) may be less discriminable than, e.g., /b/ versus /s/. Third, the pattern of the suprasegmentals may affect performance. The phonemic difference may be more salient for the young infants if changes in intonation, amplitude, and/or duration are used to highlight the sequences.

As mentioned earlier, Fernald and Kuhl (1982) found that 6-month-old infants could discriminate five-syllable sequences (viz., galasalaga versus galatalaga). The infants discriminated the sequences in both of the prosodic conditions tested, infant-directed and adult-directed speech. In comparing these results with Trehub's (1973) results, it should be pointed out that the head-turn technique used by Fernald and Kuhl (1982) may be more more sensitive than Trehub's high-amplitude sucking procedure, and that /sa/ versus /ta/ may be more discriminable than /pa/ versus /ba/.

In summary, young infants have discriminated two-syllable sequences which differ by one speech sound in a variety of phonemic contexts. The young 1- to 4-month-old infants did not demonstrate discrimination of three-syllable sequences in Trehub's (1973) study. However, Fernald and Kuhl (1982) showed that slightly older infants (4 months) clearly demonstrated discrimination of five-syllable sequences. Factors which may contribute to these differences in results include the following: technique, age of the subjects, magnitude of the phonemic difference, and suprasegmental patterning of the stimuli.

Implications for Present Research

The prior research indicates that 1- to 4-month-old infants are capable of discriminating a wide variety of speech sounds as well as some changes in suprasegmental patterns within the context of one- and two-syllable stimuli. Previous research also suggests that infants prefer speech with exaggerated suprasegmental characteristics (representative of infant-directed) to speech with suprasegmental characteristics of conversation.

The present study was designed to investigate infant discrimination of three-syllable sequences and to explore the role of suprasegmental features in discrimination performance. Since infants of 1 to 4 months of age were the focus of the study, a high-amplitude sucking procedure (described in Chapter 3) was used. The six experiments comprising the study are described in detail in Chapter 4 and summarized briefly in Chapter 5.

Chapter 3

GENERAL METHODS

An attempt was made to apply the same procedures in all six experments for subject acquisition, equipment set-up, and stimulus synthesis and presentation. General procedures will be described in this section; departures will be noted where applicable during the discussion of the individual experiments.

Equipment

The equipment set-up is schematized in Figure 1. The test booth consisted of a single-wall sound booth (Industrial Acoustics Company, Inc.) with ambient noise, at the site of the infant's head of approximately 26 dBA. The booth walls and ceiling were lined with convoluted foam (1-1/2 inch, polyurethane, open-cell) to reduce reverberation. The booth contained the following: a crib with an infant seat and smoked plexiglass projection screen; the loudspeaker for stimulus presentation; a television camera to monitor infant behavior; a monitor microphone, the synthetic nipple and pressure transducer system; and earphones to provide verbal instructions and masking noise to the assistant.

The control room contained the instrumentation necessary to control stimulus presentation and response measurement throughout the test session.

A more detailed description of the instrumentation follows.

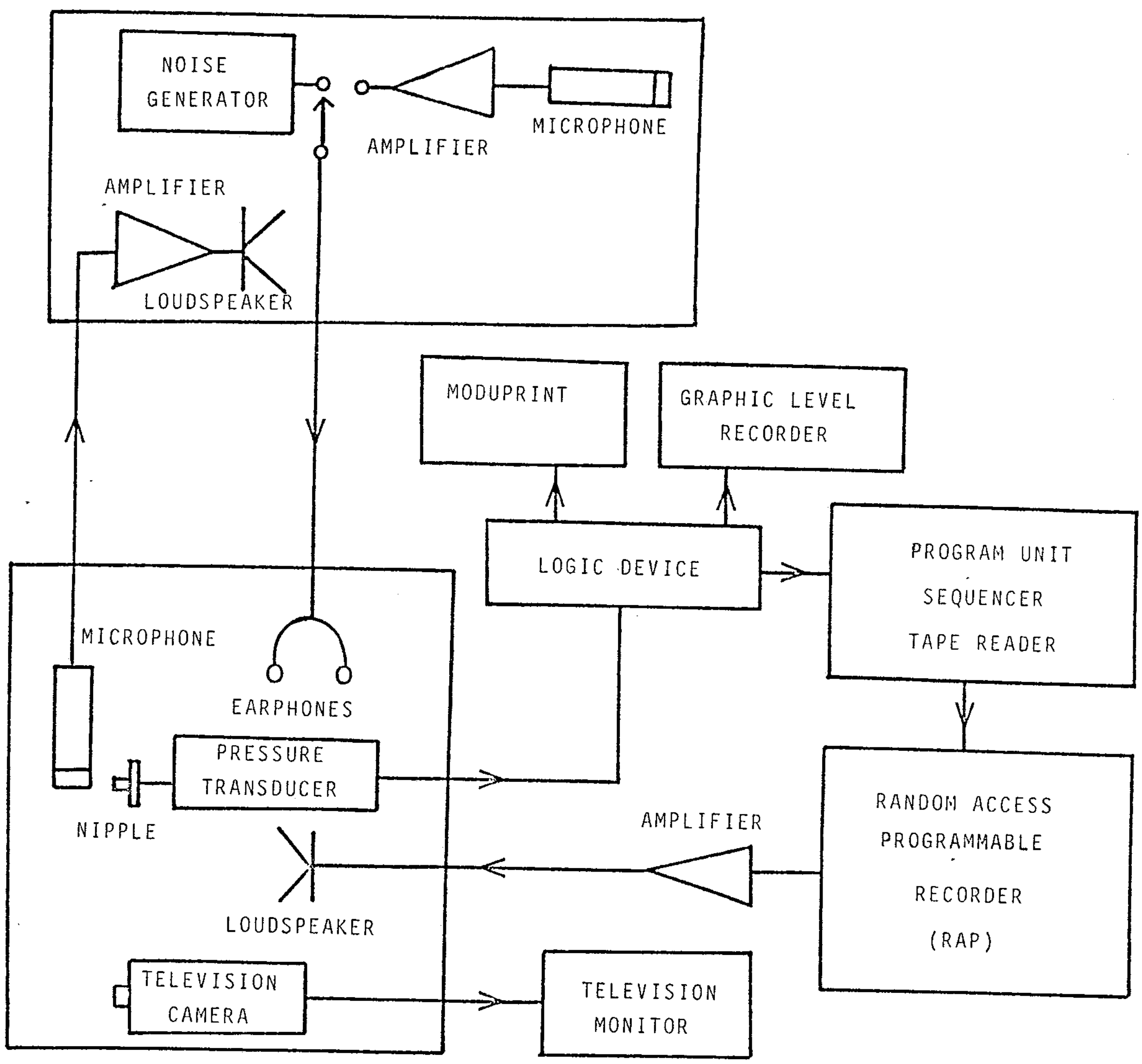

Fig. 1. Equipment set-up for the high-amplitude-sucking procedure.

Nipples and Pressure Transducer

Blind nipples, obtained from five commercial manufacturers (Nuk, Davol, Curity, Hygea and Evenflo), were attached to specially machined adaptor-rings made of nylon. These adaptor rings had a protruding tube which fit snugly into tygon tubing (type R3603). The tubing led to the pressure transducer (National Semiconductor type LX 160 1G).

Logic Device, Moduprint, and Graphic Level Recorder

The electrical signal from the pressure transducer passed to the logic device which consisted of control and printer units. The logic device was designed and constructed at Central Institute for the Deaf (C.I.D.).[7] The control unit of the device allowed for the following:

1) adjustment of the pressure threshold required for a criterion response (i.e., high amplitude suck);
2) triggering and counting the stimuli presented each minute;
3) counting and displaying the number of sucks per minute; and
4) setting of a percent decrement criterion for habituation. If the percent decrement was met for two successive minutes, the device automatically triggered the change from one sound to the other, or to the same sound stored in a different memory location (in the case of the control-group infants). The time prior to the change in sounds is referred to as pre-shift and the time after the change in sounds is referred to as post-shift. Additionally, the logic device allowed for manual shift from one sound to another.

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[7]A.M. Engebretson designed and supervised construction of the logic system.

The Moduprint unit recorded on paper tape both the number of criterion sucks and the number of stimuli presented during each experimental minute. The graphic level recorder (Sanborn 8802A) displayed an analogue of the pressure signal from the nipple, as well as marks which indicated onset and offset of the stimulus and minute intervals.

Program Unit and Random Access Programmable Recorder of Complex Sounds (RAP)

The program unit consisted of a stimulus sequencer which has a memory capacity of 16 items and a paper tape reader. All sounds for the experiment were stored on digital disk appropriate for RAP I (Spenner et al., 1973). Sounds stored in digital form in RAP I were reconstructed during playback using a 12-bit digital-to-analogue converter followed by a smoothing filter. The overall signal to noise ratio for the output signal from RAP I was 60 dB and the bandwidth was 8 KHz. The locations and durations of the stimuli were stored in memory bins of the sequencer unit. The pre-shift stimulus was stored as item one and the post-shift stimulus was stored as item nine. A coded paper tape, which was activated by the infant's sucks, drove the RAP through a two-stage cycle as follows: "play item one and pause." When the post-shift mode of the logic device was activated, an electrical reversal of current changed the cycle to "play item nine and pause."

Amplifier-Loudspeaker System

The stimulus signal from RAP passed through a 45-watt amplifier of C.I.D. construction (with a signal to noise ratio of 115 dB and a bandwidth of 3Hz to 100 KHz) and on to an 8-inch Lorenz loudspeaker which was mounted on-axis and approximately two feet from the infant's head.

The loudspeaker was selected for its flat frequency response which varies over a 7dB range from 80 to 10,000 Hz. Independent mounting of the loudspeaker precluded transmission of vibration to the crib from the loudspeaker or the booth surfaces.

Two-Way Talk and Masking System

The two-way talk and masking system consisted of the following: Realistic SA-10 Solid State Stereo Amplifier; Lafayette Dynamic Microphone (99-46161, impedance 10 K Ohms); Panasonic 16 cm loudspeaker (Model EAS-16 P93SK); broad-band noise generator (constructed at C.I.D.); and a pair of Koss Pro 4A earphones. When the system was operating, the assistant received broad-band masking noise. Pressing an override button allowed the experimenter to replace the noise generator channel with a microphone channel and thus speak directly to the assistant. The signal from a microphone mounted in the ceiling of the IAC test booth passed to a loudspeaker in the control room so that the experimenter could monitor the sounds presented, the infant vocalizations, and the speech of the assistant.

Closed Circuit Television System

A television camera (Panasonic WV-1000A) was mounted on the side of the crib approximately two feet from the infant and was focused on the infant's face. A television monitor (Sanyo VM4509) outside the booth allowed the experimenter and mother to view the behavior of the infant throughout the experimental session.

Crib and Projection Screen

The wooden crib had a 15x7 inch smoked plexiglass screen mounted approximately 20 inches from the infant's face. One of three colored transparencies was backlighted throughout the session. Two of the transparencies were pictures of faces and the other was a geometric design. All three were composed of bright colors. A commercial infant-seat was placed at the head of the crib and all infants were tested in a semireclining position.

Subjects

Initially, subjects were referred by pediatricians practicing in the St. Louis metropolitan area. Upon our request, pediatricians either posted or handed out information sheets to mothers whose pregnancies were full-term, whose deliveries were normal, and whose infants were not at risk for any reason. In some cases, the pediatrician forwarded the names and telephone number of interested mothers. In other cases, interested mothers were told to contact the project staff directly.

Since too few subjects were obtained with this physician referral method, arrangements were made at four hospitals in the St. Louis metropolitan area for us to contact mothers during their maternity stay. In each hospital approval was granted by the appropriate review committee. The experimenter or an assistant visited each hospital two or three times each week. Infants were selected from the well-baby nurseries according to five basic criteria: 1) APGAR scores of at least 7 at both 1 and 5 minutes; 2) birthweight between 2500 and 4000 grams; 3) gestation between 38 and 42 weeks; 4) total bilirubin of less than 12 mg%; and 5) permission granted by the attending pediatrician to visit the mother of the infant.

Infants were excluded if the medical history revealed problems known to be correlated with hearing impairment, e.g., Rh incompatibility. After checking the medical records, the research staff member visited the selected mothers. During the brief visit (3 to 5 minutes), the procedure was described and questions concerning the experiment were answered. If the mother expressed an interest in participating, she was given a one page information sheet (see Appendix A) and her name, address and telephone number were recorded. Later, when the infant was approximately 4 to 6 weeks of age, each mother was contacted to arrange an appointment time. Mothers were asked to schedule at a time when the infant would be "awake and happy." Appointments were usually scheduled between 9:00 a.m. and 5:00 p.m. Typically, 45 minutes was allotted for each appointment. Prior to testing, the parent accompanying the infant signed a consent form (see Appendix A) which differed depending on the hospital referral source.

Stimuli

Phoneme Selection

A wider range of possible stimuli were considered before making the final choice of /ra,la,ma,na/. Use of consonant duration as a variable precluded selection of stop-plosive consonants, whose timing characteristics are restricted. Fricatives were excluded due to reported negative findings with certain fricatives in single syllable contexts by Eilers (1977) and Eilers and Minifie (1975). Thus, consonant sounds were selected from among the continuant consonants, i.e., liquids, glides and nasals.

The /ra/ and /la/ phonemes were selected for the point of contrast for all six experiments. The /ma/ and /na/ sounds were chosen for syllables 1 and 3 in the three-syllable stimuli presented in Experiments II through VI.

The vowel selected for the series of experiments, i.e., /a/, was chosen because it had been frequently used in previous studies. Therefore, it provided continuity with prior work and made comparison of results more plausible.

Sound Synthesis

The four syllables used in the experiments were synthesized using Klatt's (1980) model in conjunction with readily available C.I.D. subroutines. The program for synthesis normalizes the sounds to maximize the signal to noise ratio at the output of the RAP I system. Fundamental frequency, formants, and bandwidths were allowed to vary as a function of time. Values for fundamental frequency, duration, and amplitude emerged from three sources: 1) selected published reports[8]; 2) analysis of five female talkers with the C.I.D. Speech Microscope (Vemula et al., 1979); and 3) Dennis H. Klatt, Ph.D. These three parameters (fundamental frequency, duration and intensity) varied systematically throughout the set of experiments. The values used in each experiment will be given as each specific sitmulus condition is discussed.

Initially, six syllables-- /ra, la, ma, na, ya/-- were synthesized and stored on digital disk. Each syllable was generated with a rising,

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[8]E.g., Pickett, 1980; Lehiste, 1970; Morton and Jassem, 1965; Fry, 1955, 1958, 1968; McClean and Tiffany, 1973; Gay, 1978; Fernald, 1978, 1981; Umeda, 1975, 1977.

falling, and rising-falling contour for fundamental frequency. Sequencing the syllables with rising, rising-falling, and falling contours for fundamental frequency resulted in an overall intonation contour which was "bell-shaped" as shown in Figure 2. The RAP III computer system with the Parapet Program (Engebretson, 1977; Hakkinen and Engebretson, 1979) was used to place the individual syllables in a three syllable sequence with 3- or 4-msec. inter-syllable intervals. Two series of syllables were synthesized: one with values of fundamental frequency typical of adult-directed speech and another with values typical of infant-directed speech. Target values of the intonation contours for both speech styles are shown in Table 5.

Three-syllable combinations of the sounds (e.g., /malaya/, /mayawa/) were synthesized and presented informally to two adult listeners. For both listeners the /ya/ and /wa/ interacted with and "colored" the perception of the preceding /a/ sound. Avoiding these sounds precluded possible problems due to this interaction. Therefore, the list of usable sounds consisted of /r, l, n, m,/ in syllables with the form consonant-/a/.

Sequence Length. In Experiment I single-syllable stimuli, /ra/ and /la/, were presented. The number of syllables per sequence for Experiments II through VI was based on the findings of previous research. In order to demonstrate improvement in performance (which was the goal of Experiment III, IV and VI), it was necessary to select stimuli which failed to elicit recovery of the sucking response for Experiment II. Phonemic differences were discriminated in two-syllable sequences by infants in studies reported by Trehub (1973), Jusczyk et al. (1977), and Jusczyk and Thompson (1978). Trehub (1973) found that

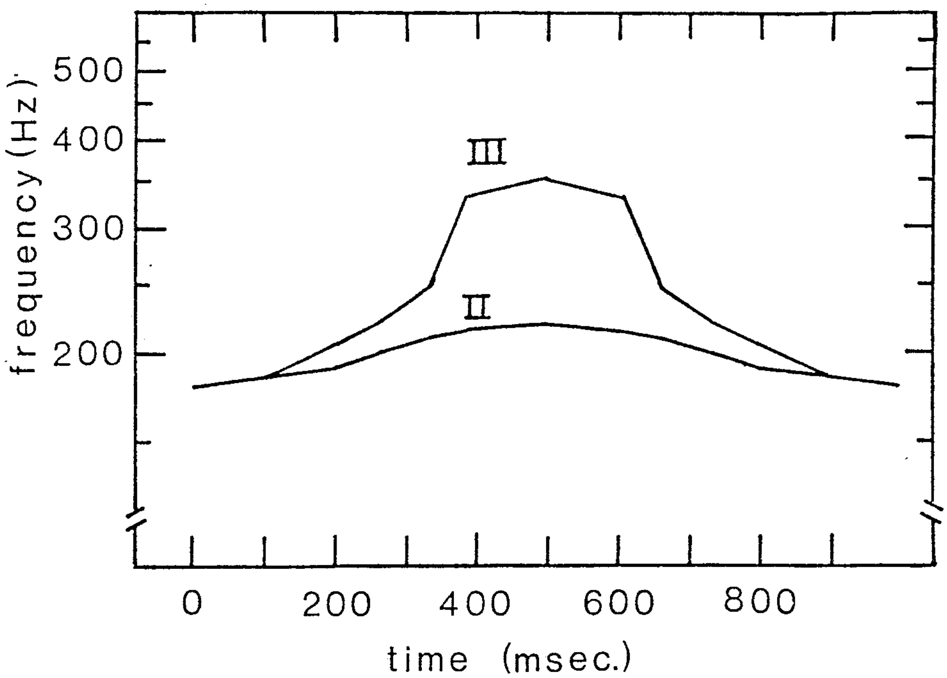

Fig. 2. Fundamental frequency as a function of time. Values employed in Experiments II and III are shown: II-- fundamental frequency contour for Experiment II; and III-- fundamental frequency for Experment III.

Table 5.

Target Values for the Intonation Contours
of Three-Syllable Sequences

Frequency Contour	Target Values in Hz		
	Begin	Middle	End
Adult-Directed Speech Style			
1. Rise....................	180	190	210
2. Peak....................	210	220	210
3. Fall....................	210	190	180
Infant-Directed Speech Style			
4. Rise....................	180	205	247
5. Peak....................	247	350	247
6. Fall....................	247	205	180

young infants failed to demonstrate discrimination of the three-syllable sequences /atapa/ versus /ataba/. Therefore, three-syllable sequences were chosen for this series of experiments that involve manipulation of fundamental frequency, duration and intensity.

Position of Sound Contrast. In order to avoid possible primacy or recency effects, the point of contrast was placed in the middle syllable of the three-syllable sequences. The nasal sounds /ma/ and /na/ were selected to surround the /ra/ versus /la/ contrast; thus, the stimuli presented in Experiments II through VI were /marana/ versus /malana/.

Procedure

Response measurement relied upon the high-amplitude sucking technique within a habituation-dishabituation paradigm. The exact protocol most resembles that used by Kuhl (1976) and Kuhl and Miller (1982).

Infants were tested individually in a single-wall, sound-controlled booth. The infant was placed in a commercial infant seat at the head of the experimental crib. One of the colorful transparencies on the screen in front of the infant provided a mild visual stimulus which presumably functioned to focus the infant's gaze directly forward. However, head movement of the infants was not restrained and frequently infants turned toward the assistant or the television camera. White cloth draped around the crib provided a homogeneous visual background.

An assistant, seated to the side of the infant, held a sterile blind nipple in the infant's mouth. During the initial baseline stage of the experiment, the assistant encouraged acceptance of the pacifier and initiation of sucking behavior. Once the infant began sucking, the experimenter adjusted the threshold setting of the logic device to establish the criterion for a high-amplitude suck. After adjustment of the criterion-threshold level, the baseline sucking rate was monitored for one minute to ensure that the criterion of 20 to 35 sucks per minute had been met. After checking the baseline criterion, the presentation of stimuli was made contingent upon the rate of high-amplitude sucking. A "stimulus time window" was selected so that once a high-amplitude suck triggered a stimulus presentation, another suck could not interrupt the stimulus for the duration of the selected window. For example, in Experiment I a given high-amplitude suck triggered a 350 msec. sound and a 400 msec. silence. Any high-amplitude sucks which occurred after the trigger suck and during the 750 msec. time window were ignored by the sound-triggering system. The values for the stimulus and time windows for Experiments I to VI were as shown in Table 6.

The initial pre-shift stimulus was presented until the rate of high-amplitude sucking dropped for two consecutive minutes to a value 20% below the maximum rate achieved in any of the previous minutes during sound presentation. After this habituation criterion was met (given that the infant had been sucking for at least four minutes), the logic device was switched to the post-shift mode and a change to the post-shift stimulus occurred. After the post-shift stimulus was presented for four minutes, the session was terminated.

Statistical Analysis

Two response measures for the pre-shift portion of the experiment were analyzed: 1) the number of sucks during the criterion minute;

Table 6

Timing Characteristics for the Stimuli of Experiments I to VI

Experiment	Stimulus Duration (msec.)	Time Window (msec.)	Minimum Intersound Interval (msec.)
I	350	750	400
II	996	1000	4
IIIa	996	1000	4
IIIb	996	1500	504
IV	1068	1500	432
V	722	1000	278
VI	1068	1500	432

and 2) the mean of the response rate during the last two pre-shift minutes. The rates were first converted into percent of the maximum pre-shift sucking rate. Each of these measures was then subjected to a one-way analysis of variance (response measure by group). Since infants in both the control and experimental group received the same treatment during the pre-shift portion of the experiment, no significant differences were expected in the two pre-shift response measures.

Performance across the shift-point of the session was indexed by calculating a "difference score". The difference score for a given subject was obtained by subtracting the mean sucking rate for the two minutes prior to the shift (pre-shift 1 and 2) from the mean of the first two minutes after the shift (post-shift 1 and 2). If infants were capable of discriminating the two stimuli and were appropriately motivated, the sucking rate of the experimental group infants increased upon the shift to the novel stimulus. The sucking rates of the infants in the control group, who continued to hear the same sound after the shift point, usually stayed about the same or decreased slightly. In fact, difference scores were typically near 0% change for the control group and greater than approximately +15% change for the experimental group if the infants discriminated the sounds. The difference scores were subjected to a one-way analysis of variance (difference score by group). If the difference scores of the experimental and control group differed significantly, it was inferred that the infants were capable of discriminating the pre- and post-shift stimuli.

Chapter 4

EXPERIMENTS

Experiment I: Discrimination of /ra/ versus /la/ by 1- to 4-month-old Infants

Using synthetic sounds modeled on vocal characteristics of male talkers, Eimas (1975b) found that 2- to 3-month-old infants demonstrated discrimination of /ra/ versus /la/. Because primary caretakers of young infants are usually women, the speech sounds in the present experiment were based on characteristics typical of female talkers. The purpose of this first experiment was to replicate Eimas's (1975b) study which indicated discrimination of /ra/ versus /la/ by young infants and to extend these results to speech sounds representative of female talkers.

Since the overall goal of this study was to assess discrimination in multisyllabic sequences, it was important to be sure at the outset that the infants were capable of discriminating the sounds to be contrasted when presented in isolation. If the infants could not discriminate the /ra/ and /la/ tokens, it was probable that they would not evidence discrimination of these sounds if they were embedded in a longer sequence. Thus, Eimas's work which indicated that infants could discriminate /ra/ versus /la/ suggests that these syllables would be appropriate for the more complex task of discriminating multisyllabic stimuli to be investigated in Experiments II through VI of this project.

Method

Subjects. Eighty infants were selected for this experiment and 32 (40%) completed the session satisfactorily. The 48 infants who failed to complete the experimental session satisfactorily were excluded for the following reasons: crying, N=30 (63%); sleep, N=7 (15%); low pre-shift sucking rate, N=4 (8%); low post-shift sucking rate, N=1 (2%); refusal to suck the pacifier, N=1 (2%); failure of the sucking rate to increase during sound presentation, N=4 (8%); and equipment failure, N=1 (2%). The average age of the 16 subjects included in the experimental group was 67.5 days (standard deviation = 16.9 days) and for the 16 subjects in the control group was 66.8 days (standard deviation = 20.1 days). Infant assignment rotated systematically through the four experimental conditions: 1)/ra/-/ra/; 2)/la/-/la/; 3)/ra/-/la/; and 4)/la/-/ra/. As the requisite number of infants was obtained in a particular condition, the condition was dropped from the rotation pattern.

Procedures and Equipment. The procedures and equipment set-up were as described in the General-Methods section of this report and are the same for all succeeding experiments (II to VI).

Stimuli. The /ra/ and /la/ syllables for Experiment I were synthesized according to the plans shown in Tables 7 and 8. Note that the fundamental frequency (F∅) contour and formant frequencies are appropriate for the female voice. The /r/ versus /l/ contrast is signaled primarily by differences in the direction and time course of formant three (F3). However, since typical values for the formants were used in the synthesis of each of these speech sounds, variations in formants one and two may serve as secondary factors in discrimi-

Table 7.

Synthesis Plan for /ra/: Experiment I

Time (msec)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	380	70	1200	100	1580	120	4200	250	180	40
20										50
70	380	70	1200	100					195	
80					1580	120				
90									200	
100										
115										60
130									220	
140	900	190								
150			1350	70						
200					2850	160				
295										60
350	900	190	1350	70	2850	160	4200	250	150	54

Table 8.

Synthesis Plan for /la/: Experiment I

Time (msec)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	380	50	1200	100	3400	280	4200	250	180	40
20										50
70	380		1200							
80									195	
95	420	50	1230	100						
100	530		1320		3400	280			200	
115										60
140	820	190							220	
150			1350	70						
160					2850	160				
200	900									
295										60
350	900	190	1350	70	2850	160	4200	250	150	54

Note. F1, F2, F3 and F4 are the center frequencies for formants one through four, respectively. B1, B2, B3 and B4 are the bandwidths associated with formants one through four, respectively. FØ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transitions from one value to another were linear with respect to time.

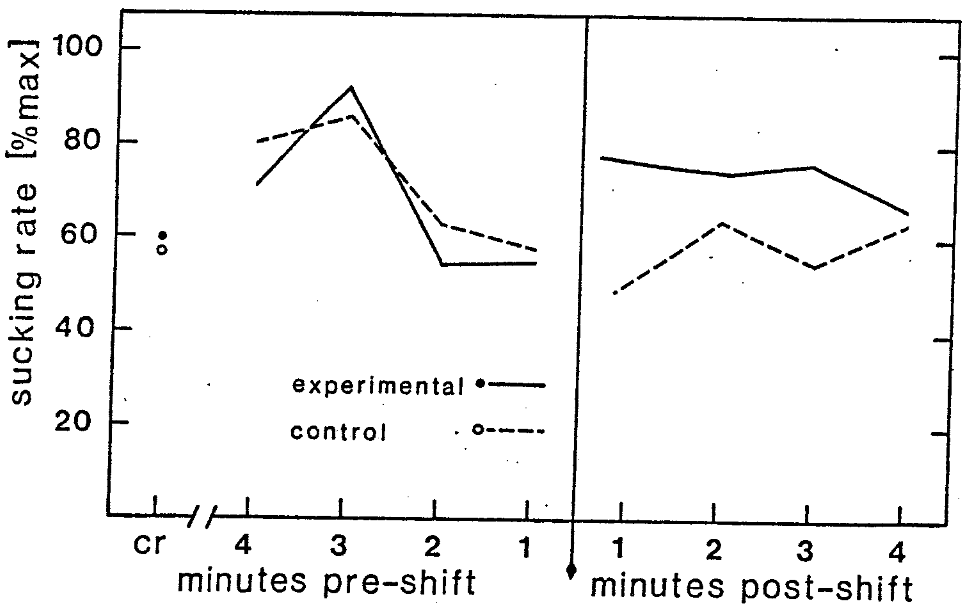

Fig. 3. Experiment I: Results of /ra/ versus /la/. (CR is the criterion minute in which all infants register 20 to 35 high-amplitude sucks.)

nation. Because the purpose of this study was to assess discrimination performance of single and multisyllabic stimuli, reduction of contrast cues to a single factor was not incorporated in the plans for synthesis.

Results and Discussion

As shown in Figure 3, the sucking rates of the experimental and control groups differed during the post-shift period. Mean difference scores for the experimental and control groups were 21.1 and -3.2, respectively. Upon a shift from /ra/ to /la/ (or vice versa), the experimental group showed an increase in sucking rate. This increase was not seen in the control group, which did not receive a sound shift. As shown in Appendix B, statistical analysis with one-way analysis of variance revealed a significant difference between difference scores of the experimental and control group; no significant difference was found between the two groups for either of the pre-shift response measures, i.e., sucking rate during the criterion minute and the mean of pre-shift minutes 1 and 2. Based on these results, it may be inferred that the infants demonstrated discrimination of the /ra/ and /la/ tokens in this experiment.

Results of this experiment confirm the earlier findings of Eimas (1975b) that young infants are able to discriminate the /r/ versus /l/ contrast. The findings extend the conditions for successful discrimination from male synthetic tokens to include female tokens. Since this experiment demonstrated that infants have the ability to discriminate the sounds when presented singly, the focus of Experiments II through VI shifted to assessment of discrimination of these sounds when they were embedded in multisyllabic sequences such as /marana/ and /malana/.

Experiment II: Discrimination of /marana/ versus /malana/ by 1- to 4-month-old Infants

As mentioned earlier, only one previous study assessed the ability of 1- to 4-month-old infants to discriminate phonemes in sound sequences longer than two syllables. Presenting natural tokens of /atapa/ versus /ataba/, Trehub (1973) found that the young infants failed to discriminate these sequences.

The purpose of Experiment II was to re-examine discrimination of three-syllable sequences by young infants. The sequences presented, /marana/ versus /malana/, differ in several ways from those used by Trehub (1973). Different speech sounds were selected for this study, i.e., /marana/ and /malana/ in contrast to /ataba/ and /atapa/ in Trehub's work. The point of contrast was in the final syllable in the Trehub (1973) study and in the middle syllable in the present study. Furthermore, stimuli for Trehub (1973) were produced by a male talker whereas stimuli for this study were generated synthetically to represent female talkers. Trehub (1973) did not report the stress pattern of the stimuli she presented. It is probable that the speakers in her study were not instructed to stress any particular syllable within the three-syllable sequences. In the present study, the synthetic tokens were carefully created to have equal syllable duration and loudness. Although the sequences of /marana/ and /malana/ had slight bell-shaped intonation contours, during informal listening tests adults heard all three syllables as having equal stress. The slight bell-shaped intonation contour was used to prevent an unnatural-sounding stimulus which would have been the case if the fundamental frequency remained constant throughout the duration of the sound.

Method

Subjects. Sixty-two infants were selected for this experiment and 32 (52%) completed the session satisfactorily. The 30 infants who failed to complete the experimental session satisfactorily were dropped from the study for the following reasons: crying, N = 14 (47%); sleep, N = 7 (23%); low pre-shift sucking rate, N = 6 (20%); low post-shift sucking rate, N = 1 (3%); refusal to suck the pacifier, N = 1 (3%); and experimenter error, N = 1 (3%). The average age of the 16 subjects in the experimental group was 61.5 days (standard deviation = 11.8 days) and for the 16 subjects in the control group was 64.3 days (standard deviation = 9.3 days). Infant assignment rotated systematically through the four experimental conditions: 1)/marana/-/marana/; 2) /malana/-/malana/; 3) /marana/-/malana/; and 4) /malana/-/marana/. As the requisite number of infants was obtained in a particular condition, the condition was dropped from the rotation pattern.

Stimuli. The sequences synthesized for Experiment II, /marana/ and /malana/, were made according to the synthesis plan shown in Tables 9 through 12. Note that the three syllables are of equal duration and that the amplitude of voicing pattern is the same for each syllable. The intonation contour rises only slightly in order to create a more natural-sounding sequence than that which would be produced with a monotone fundamental frequency. Informal listening by adults suggested that this prosodic pattern is perceived as three equally stressed syllables. As in all of the experiments, the speech sounds were modeled on female vocal characteristics. The individual syllables were synthesized separately and then sequenced with 3 msec.

Table 9.

Synthesis Plan for /ra/: Experiment II

Time (msec)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	380	70	1200	100	1580	120	4200	250	210	40
20										50
60									215	
70	380	70	1200	100						
80					1580	120				
115										60
140	900	190								
150			1350	70						
165									220	
200					2850	160				
270									215	
295										60
330	900	190	1350	70	2850	160	4200	250	210	54

Table 10.

Synthesis Plan for /la/: Experiment II

Time (msec)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	380	50	1200	100	3400	280	4200	250	210	40
20										50
60									215	
70	380		1200							
95	420	50	1230	100						
100	530		1320		3400	280				
115										60
140	820	190								
150			1350	70						
160					2850	160				
165									220	
200	900									
270									215	
295										60
330	900	190	1350	70	2850	160	4200	250	210	54

Note. F1, F2, F3, and F4 are the center frequencies B1, B2, B3, and B4 are the bandwidths associated with formants one through four, respectively. FØ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transitions from one value to another were linear with respect to time.

Table 11.

Synthesis plan for /ma/: Experiment II

Time (msec)	FNP (Hz)	BNP (Hz)	FNZ (Hz)	BNZ (Hz)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (Hz)
0	280	100	520	100	550	80	1120	180	2600	50	4200	250	180	40
20														50
85			520		550		1120	180	2600	50				
90			450		630	80	1230	70	2720	140				
100													185	
115														60
120					900	190								
130			280											
150									2850	160				
160							1350							
200													190	
260													200	
295														60
330	280	100	280	100	900	190	1350	70	2850	160	4200	250	210	54

Note. The center frequency and bandwidth of the nasal pole are denoted by FNP and BNP, respectively. The center frequency and bandwidth of the nasal zero are denoted by FNZ and BNZ, respectively. F1, F2, F3, and F4 are the center frequencies and B1, B2, B3, and B4 are the bandwidths associated with formants one through four, respectively. FØ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transitions from one value to another were linear with respect to time.

Table 12.

Synthesis Plan for /na/: Experiment II

Time (msec)	FNP (Hz)	BNP (Hz)	FNZ (Hz)	BNZ (Hz)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	280	100	520	100	550	80	1300	300	2750	300	4200	250	210	40
20														50
70													200	
85			520		550		1300	300	2750	300				
90			450		600	80	1650	130	2850	250				
115														60
120					900	190								
130													190	
140							1350	70		160				
230													185	
240			280											
295														60
330	280	100	280	100	900	190	1350	70	2850	160	4200	250	180	54

Note. The center frequency and bandwidth of the nasal pole are denoted by FNP and BNP, respectively. The center frequency and bandwidth of the nasal zero are denoted by FNZ and BNZ, respectively. F1, F2, F3, and F4 are the center frequencies and B1, B2, B3, and B4 are the bandwitdths associated with formants one through four, respectively. FØ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transitions from one value to another were linear with respect to time.

of silence between syllables. The minimum intersound interval during stimulus presentation was 4 msec.

Results and Discussion

As shown in Figure 4, the sucking rates of the experimental and control groups do not appear to differ significantly during the post-shift period. Although not statistically significant, the mean difference scores for the control and experimental groups were 0.13 and 14.13, respectively. As shown in Appendix B, analyses of variance indicate that there is not a significant difference between groups for any of the pre-shift (sucking rate during the criterion minute and mean of pre-shift minutes 1 and 2) or post-shift (difference scores) response measures. Thus, the infants tested did not demonstrate discrimination of /marana/ and /malana/ in the conditions of this experiment.

Results of this experiment support Trehub's earlier findings; infants failed to demonstrate discrimination of three-syllable sequences which differ by one speech sound. They did not show evidence of discriminating /ataba/ versus /atapa/ in the Trehub (1973) experiment, nor /marana/ versus /malana/ in the present experiment. These two studies do not preclude the possibility that with different speech sounds or placement of the contrast, infants may demonstrate discrimination of three-syllable sequences with equal syllable stress.

Because of observations of infant-directed speech and the possible role prosody may play in infant attention and/or comprehension, it was suspected that stressing the syllable containing the contrast would facilitate discrimination. This hypothesis was tested in Experiments III, IV, V and VI.

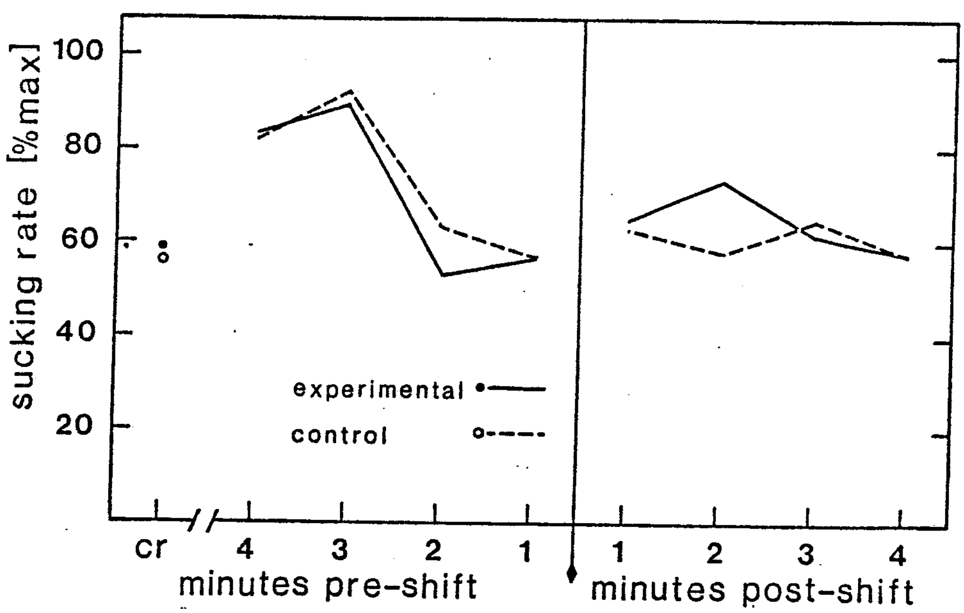

Fig. 4. Experiment II: Results of /marana/ versus /malana/. Equal amplitude of voicing and duration for all syllables. (CR is the criterion minute in which all infants register 20 to 35 high-amplitude sucks.)

Experiment III: Discrimination of /marana/ versus /malana/ with an infant-directed intonation contour

Results with /marana/-/malana/ and /ataba/-/atapa/ (Trehub, 1973) at first glance suggest that young infants do not demonstrate discrimination of three-syllable sequences which differ by one speech sound. However, there may be certain conditions in which young infants may readily discriminate three-syllable sequences. For example, if presented with sounds which differ in both place and manner of articulation (e.g., /marana/ versus /masana/), the contrast may be more discriminable. The decision to investigate suprasegmental parameters was made on the basis of research on characteristics of speech addressed to infants and young children. When addressing infants, speakers tend to exaggerate suprasegmental aspects of the utterance: larger excursions in the intonation contour, greater intensity changes, longer duration, etc.

Many researchers have speculated that these characteristics of infant-directed speech are functional for the infant. They may serve to attain/maintain attention in general (Sachs et al., 1976; Garnica, 1977; Sachs, 1977; Fernald, 1978; Blount and Padgug, 1976; Snow, 1977b; Chapman, 1981) or they may function more specifically to highlight important distinctions within the sound sequence. According to Fernald (1978, p 9.) prosody patterns increase "the potential for acoustic contrast among linguistic elements within the utterance." If Fernald's hypothesis is correct, it seems plausible that stress on the syllable which contains the phonemic contrast may make the three-syllable sequences may become more readily discriminable for young infants. Since intonation is considered by many to be the primary cue for stress in English (Bolinger 1958), the fundamental frequency contour was the parameter selected for manipulation.

Based on the published literature and measurements of the speech of five females, the /marana/ and /malana/ sequences were resynthesized with intonation contours peaking markedly in the middle syllables of both sequences. The pitch contour, which was identical for both /marana/ and /malana/, rose and fell in a bell-shaped pattern over nearly a one-octave range. Except for these exaggerated pitch contours, the sequences were the same as those used in Experiment II. It was hypothesized that the exaggerated pitch contour, typical of speech directed to infants, would enable the infants to focus on the distinctive middle syllables and detect a change in speech sounds embedded within the three-syllable tokens.

In addition to assessing the ability of young infants to demonstrate discrimination of multisyllabic sequences with exaggerated intonation, the effects of varying the minimum intersound interval were investigated in Experiments IIIa and IIIb.

Method

Subjects. Seventy infants were selected for this experiment and 32 (46%) provided usable data. The 38 infants who failed to complete the session satisfactorily were excluded for the following reasons: crying, N=22 (56%); sleep, N=5 (13%); failure of the sucking rate to increase during sound presentation, N=4 (10%); refusal of the pacifier, N=6 (16%), and low pre-shift sucking rate, N=1 (3%). First, Experiment IIIa with a short minimum intersound interval was carried out with 16 experimental infants whose mean age was 59.5 days (standard deviation =

12.7 days). Later, Experiment IIIb with a long minimum intersound interval was carried out with 16 experimental infants whose mean age was 76.1 days (standard deviation = 12.1 days). In both IIIa and IIIb subjects were assigned to one of the two experimental conditions, 1) /marana//malana/ or 2) /malana/-/marana/, on a predetermined and systematic basis.

Stimuli. The /marana/ and /malana/ sequences for Experiments IIIa and IIIb had the same formant frequencies, bandwidths, and amplitude of voicing as those of Experiment II (see Tables 9 through 12). The fundamental frequency contours for both sequences were identical and differed markedly from those of Experiment II. As shown in Figure 2, the intonation contour for the sequences of Experiments IIIa and IIIb was exaggerated relative to that of Experiment II. The same stimulus sequences were used in both IIIa and IIIb; however, the minimum intersound intervals were different. Minimum-intersound intervals were 4 msec. and 504 msec. for IIIa and IIIb, respectively.

Results and Discussion

Despite the exaggerated intonation contour which peaked on the syllable of contrast, results of Experiments IIIa and IIIb failed to provide evidence of discrimination of the /marana/ and /malana/ sequences. Performance of the experimental group from Experiments IIIa and IIIb was analyzed to see if the difference in minimum intersound interval (4 msec. in IIIa versus 504 msec. in IIIb) was a significant factor. As shown in Appendix B, analysis of variance of the two pre-shift variables revealed no significant differences between the two groups for the sucking rate during the criterion minute and for the mean of the two habituation minutes. An analysis of variance on the difference scores revealed no significant difference between the experimental infants of IIIa and IIIb. It appears that minimum intersound intervals as disparate as 4 and 504 msec. do not significantly influence performance in this condition.

As shown in Appendix B, performance of experimental groups IIIa and IIIb was compared statistically with that of control groups from Experiments II and IV. The control groups from Experiments II and IV were selected for comparison purposes because the stimuli employed were similar with respect to number of syllables, syllable duration and spectral content. Comparisons were made between the following: 1) IIIa experimental versus II control; 2) IIIb experimental versus II control; 3) IIIa + IIIb experimentals versus II + IV controls. In each of these three instances, no significant differences (criterion of $p<.05$) were found between the experimental and control groups for any of the three response measures (i.e., sucking rate during the criterion minute; mean sucking rate of pre-shift minutes 1 and 2; and difference scores). Although combining experimental groups IIIa and IIIb in comparison with control groups II and IV (see Figure 5) doubled the sample size, difference scores failed to reach statistical significance at the .05 level ($p=.08$, $F=3.07$, $df=1/62$).

Since it was presumed that the infant-directed intonation contour provided in this experiment would facilitate discrimination of /marana/ versus /malana/, it surprised the author to find no evidence of discrimination. By way of explanation there is always the possibility with the high-amplitude sucking technique that infants are capable of

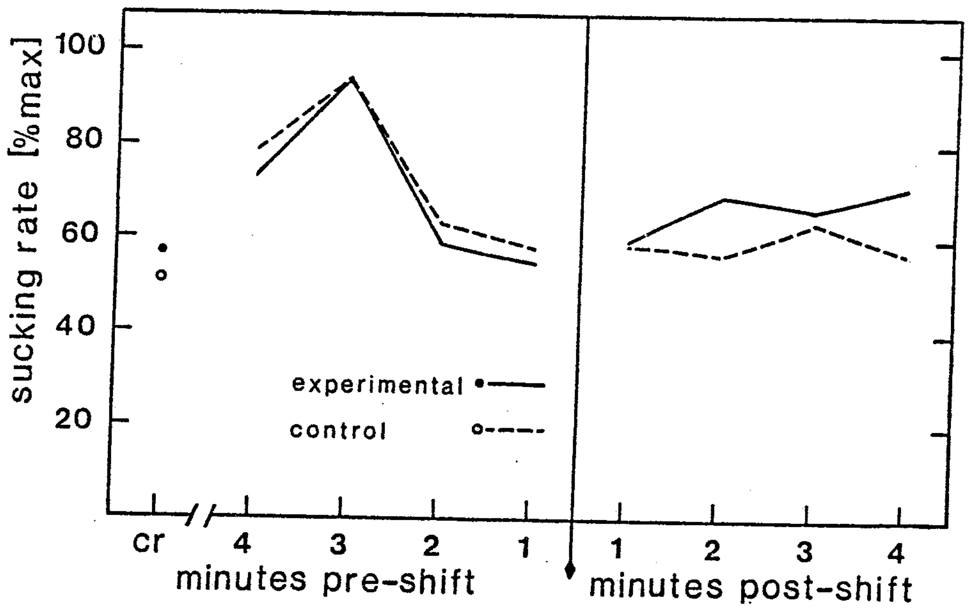

Fig. 5. Experiment III: Results of /marana/ versus /malana/. Equal amplitude of voicing and duration for all syllables. Infant-directed intonation which peaks on the middle syllable of both sequences. (CR is the criterion minute in which all infants register 20 to 35 high-amplitude sucks.). The experimental group is comprised of infants from experiments IIIa and IIIb; the control group represents infants from experiments II and IV.

making the distinction, but that the procedure lacks sensitivity, i.e., performance is poorer than competence. An alternative explanation is that perhaps pitch alone was insufficient to enhance discriminability. Syllabic stress in naturally-spoken speech is typically signaled by a combination of intonation, loudness, and duration changes, not by a single parameter alone. Possibly, the exaggerated intonation contour, in the absence of secondary loudness and duration cues, was inappropriate because it is not representative of naturally-occuring suprasegmental patterns. The testable explanation, that pitch alone was insufficient, was explored in Experiments IV and V. In these later experiments stimuli were synthesized with all three correlates of syllabic stress -- pitch, loudness and duration.

The minimum intersound interval did not seem to affect performance on the task of discriminating /marana/ and /malana/ with exaggerated intonation. However, since Experiments IV, V and VI were designed to investigate three-syllable sequences, minimum intersound intervals greater than 250 msec. were employed. This longer intersound interval ensured the perception of 3-syllable sequences rather than sequences of multiple lengths, e.g., 6, 9 or 12 syllables.

Experiment IV: Discrimination of /marana/ versus /malana/ with infant-directed intonation, loudness, and duration

In Experiment III infants failed to provide evidence of discrimination for /marana/ versus /malana/ given an exaggerated intonation contour typical of infant-directed speech highlighting the embedded phonemic contrast. If the intonation contour alone was insufficient to highlight appropriately the distinctive middle syllable, perhaps the use of infant-directed cues for all three acoustic correlates of stress--i.e., intensity, frequency and duration--would provide the necessary highlighting to enable young infants to discriminate the sequences. Accordingly, Experiment IV provided identical suprasegmental stress cues representative of infant-directed speech to both /ra/ and /la/ embedded within the three-syllable sequences /marana/ and /malana/. It was hypothesized that this suprasegmental highlighting would enhance the phonemic contrast and that the infants would demonstrate discrimination of the sequences in the conditions of this experiment.

A precondition for this experiment was solving the problem of creating synthetic speech which sounds natural and which is representative of female speech spoken in the infant-directed style. The range of the fundamental frequency extended from 180 to 350 Hz and was the same as that used in Experiment III. This excursion of approximately 11 semitones was based on values reported in Fernald (1978). Values for relative amplitude of the syllables and for duration of the consonant and vowel components of the middle syllable were based on extrapolation from the adult literature (see Appendix C) and interpretation of subjective observations from the infant literature as well as from informal analysis of the highly prosodic utterances of five female talkers with the Speech Microscope (Vemula et al. 1979).

Method

Subjects. Seventy-four infants were selected for this experiment and 32 (44%) completed the session satisfactorily. The 42 infants excluded were dropped from the study for the following reasons:

crying, N=27 (64%); sleep, N=8 (19%); low pre-shift sucking rate, N=6 (14%); and refusal to suck the pacifier, N=1 (2%). The average age of the 16 infants included in the experimental group was 62.2 days (standard deviation = 13.8 days) and in the control group was 64.8 days (standard deviation = 15.0 days). Infant assignment rotated systematically through the four experimental conditions: 1) /marana/-/marana/; 2) /malana/-/malana/; 3) /marana/-/malana/; and 4) /malana/-/marana/. As the requisite number of infants was obtained in a particular condition, the condition was eliminated from the rotation schedule.

Stimuli. The /ra/ and /la/ components for the sequences, /marana/ and /malana/, were synthesized according to the plans shown in Tables 13 and 14. The /ma/ and /na/ components were the same as those synthesized for Experiment II except for the fundamental frequency contours which were as shown in Table 15.

In order to provide a smooth transition to and from the middle syllable , the fundamental frequency of /ma/ and /na/ differed from that of Experiments IIIa and IIIb. Although the amplitude of voicing pattern is the same for all four syllables, later acoustic shaping reduced the surrounding syllables, /ma/ and /na/, by 5 decibels relative to the point of contrast syllables, /ra/ and /la/. Thus, stimuli in this condition include three physical cues to highlight the middle syllable which contains the phonemic contrast; the middle syllable is longer (400 msec. in contrast to 330 msec.), more intense (5 dB greater than the first and last syllables), and higher pitched (contains the peak of the exaggerated intonation contour). A time window of 1500 msec. was selected for Experiment IV; therfore the

Table 13.

Synthesis Plan for /ra/: Experiment IV

Time msec)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	F∅ (Hz)	AV (dB)
0	380	70	1200	100	1580	120	4200	250	247	40
40										50
90	380	70	1200	100						
100					1580	120			330	
115										60
160	900	190								
170			1350	70						
200									350	
220					2850	160				
295										60
300									330	
400	900	190	1350	70	2850	160	4200	250	247	54

Table 14.

Synthesis Plan for /la/: Experiment IV

Time msec)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	F∅ (Hz)	AV (dB)
0	380	50	1200	100	3400	280	4200	250	247	40
40										50
90	380		1200							
100									330	
115	420	50	1230	100						60
120	530		1320		3400	280				
140	820	190								
150			1350	70						
160					2850	160				
200	900								350	
295										60
300									330	
400	900	190	1350	70	2850	160	4200	250	247	54

Note. F1, F2, F3, and F4 are the center frequencies and B1, B2, B3, and B4 are the bandwidths associated with formants one through four, respectively. F∅ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transition from one value to another were linear with respect to time.

Table 15.

Fundamental Frequency Values for /ma/ and /na/: Experiment IV

Syllable	Time (msec.)				
	0	60	165	270	330
/ma/	180 Hz	185 Hz	205 Hz	220 Hz	247 Hz
/na/	247 Hz	220 Hz	205 Hz	185 Hz	180 Hz

minimum intersound interval was 432 msec.

Results and Discussion

As shown in Figure 6, the sucking rates of the experimental and control groups differed markedly during the post-shift period. Upon a shift from /marana/ to /malana/ (or vice versa), the experimental group showed an increase in sucking rate. This increase was not seen in the control group, which heard either /marana/ or /malana/ throughout the entire period of sound presentation. The analysis of variance (see Appendix B) revealed a significant ($p<.01$) difference between the control and experimental groups for difference scores; mean difference scores were -4.78 and 24.56 for the control and experimental groups, respectively. No significant differences were found between the groups for either of the pre-shift response measures (sucking rate during the criterion minute and mean sucking rate for pre-shift minutes 1 and 2). These statistical findings indicate that infants are capable of discriminating /marana/ versus /malana/ in the conditions of this experiment.

Given the exaggerated suprasegmental contours typical of infant-directed speech, infants show clear evidence of discriminating sequences of three syllables which differ by only one speech sound. It appears that young infants are capable of discriminating three-syllable sequences if sufficient stress in the form of increased duration, pitch and loudness is placed on the contrastive syllable. It is tempting to speculate that the exaggerated suprasegmental parameters of infant-directed speech facilitated discrimination by focusing the

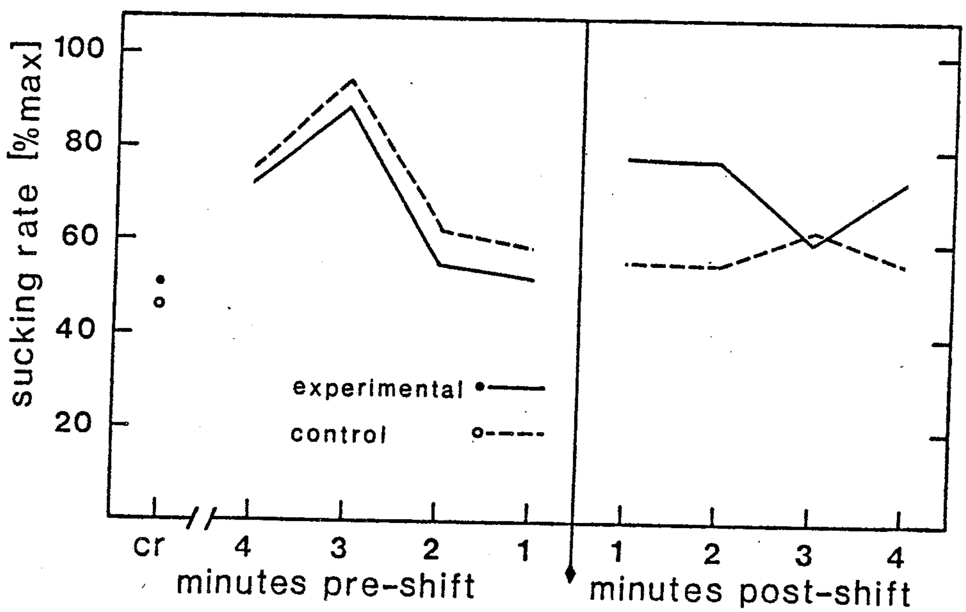

Fig. 6. Experiment IV. Results of /marana/ versus /malana/. Infant-directed values for fundamental frequency, relative amplitude, and duration. (CR is the criterion minute in which all infants register 20 to 35 high-amplitude sucks.)

infant's attention on the distinctive middle syllable in the /marana/-/malana/ sequences.

Although at this point in the series of experiments we know that the combined suprasegmental aspects of infant-directed speech were sufficient for discrimination, we do not know whether they were necessary. Infants may also be capable of discriminating three-syllable sequences given suprasegmental characteristics typical of adult-directed speech with stress on the distinctive syllable. Therefore, before extolling the virtues of infant-directed speech, Experiment V was planned to investigate performance in the condition of adult-directed stress to highlight /ra/ and /la/ within the three-syllable stimuli /marana/ and /malana/.

Experiment V: Discrimination of /marana/ versus /malana/ with adult-directed intonation, loudness and duration

In Experiment V the synthetic sequences, /marana/ and /malana/, were created to represent adult conversational speech. As in Experiment IV, pitch, loudness and duration served to stress or highlight the middle syllables, /ra/ and /la/. However, in this experiment the physical correlates of stress were representative of adult-directed suprasegmental patterns. The rationale for choosing the selected values of fundamental frequency, duration and relative amplitude is discussed in Appendix C.

The positive results of Experiment IV suggested that infants are capable of discriminating three-syllable sequences which differ by one speech sound. The purpose of this experiment was to determine whether the exaggerated suprasegmental characteristics of Experiment IV were necessary for discrimination or whether a typical adult-directed stress pattern would be sufficient to elicit post-shift recovery of sucking rate for the experimental group.

Method

Subjects. Sixty-seven infants were selected for this experiment and 32 (48%) provided usable data. The 35 infants who did not satisfactorily complete the test session were excluded for the following reasons: crying, N=18 (53%); sleep, N=10 (29%); failure to increase sucking rate during sound presentation, N=3 (9%); low pre-shift sucking rate, N=2 (6%); refusal to suck the pacifier, N=1 (3%); and experimenter error, N=1 (3%). The mean age of the 16 infants of the experimental and control groups was 68.4 days (standard deviation = 11.1 days) and 68.8 days (standard deviation = 10.1 days), respectively. Infant assignment rotated systematically through the four experimental conditions: 1) /marana/-/marana/; 2) /malana/-/malana/; 3) /marana/-/malana/; and 4) /malana/-/marana/. When eight complete and satisfactory sets of data were obtained in a particular condition, it was withdrawn from the rotation pattern.

Stimuli. Synthesis plans for the syllable components of the sequences (i.e., /ra, la, ma, na/) are shown in Tables 16 through 19. After synthesis the syllables were sequenced with 4 msec. silences between adjacent syllables to form /marana/ and /malana/ sequences. Values for the three primary physical correlates of stress were selected to highlight the middle syllable which contained the phonemic contrast. First, with respect to intensity, acoustic shaping reduced by 2 dB the overall intensity of the unstressed /ma/ and /na/ syllables

Table 16

Synthesis Plan for /ra/: Experiment V

Time (msec)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	380	70	1200	100	1580	120	4200	250	230	40
20										50
38	380	70	1200	100						
48					1580	120				
68									250	
108	900	190								60
118			1350	70						
135									255	
168					2850	160				
200										60
202									250	
270	900	190	1350	70	2850	160	4200	250	230	54

Table 17

Synthesis Plan for /la/: Experiment V

Time (msec)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	380	50	1200	100	3400	280	4200	250	230	40
20										50
25	380		1200		3400					
50	420	50	1230	100						
55	530		1320			280				
65					2850					
68									250	
75	820	190								
85			1350	70						
95						160				
108										60
135	900								255	
200										60
202									250	
270	900	190	1350	70	2850	160	4200	250	230	54

Note. F1, F2, F3, and F4 are the center frequencies and B1, B2, B3, and B4 are the bandwidths associated with formants one through four, respectively. FØ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transitions from one value to another were linear with respect to time.

Table 18.

Synthesis Plan for /ma/: Experiment V

Time (msec)	FNP (Hz)	BNP (Hz)	FNZ (Hz)	BNZ (Hz)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	280	100	520	100	550	80	1120	180	2600	50	4200	250	220	40
20														50
46			520		550		1120	180	50	50				
51			450		630	80	1230	70	2600	140				
67													222	
81					900	190								
85														60
91			280											
111									2850	160				
121							1350							
135													224	
164														60
175													227	
222	280	100	280	100	900	190	1350	70	2850	160	4200	250	230	54

Note. The center frequency and bandwidth of the nasal pole are denoted by FNP and BNP, respectively. The center frequency and bandwidth of the nasal zero are denoted by FNZ and BNZ, respectively. F1, F2, F3, and F4 are the center frequencies and B1, B2, B3, and B4 are the bandwidths associated with formants one through four, respectively. FØ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transitions from one value to another were linear with respect to time.

Table 19.

Synthesis Plan for /na/: Experiment V

Time (msec)	FNP (Hz)	BNP (Hz)	FNZ (Hz)	BNZ (Hz)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	280	100	520	100	550	80	1300	300	2750	300	4200	250	230	40
20														50
46			520		550		1300	300	2750	300				
47													227	
51			450		600	80	1650	130	2850	250				
81					900	190								
85														60
87													224	
101							1350	70		160				
155													222	
164														60
201			280											
222	280	100	280	100	900	190	1350	70	2850	160	4200	250	220	54

Note. The center frequency and bandwidth of the nasal pole are denoted by FNP and BNP, respectively. The center frequency and bandwidth of the nasal zero are denoted by FNZ and BNZ, respectively. F1, F2, F3, and F4 are the center frequencies and B1, B2, B3, and B4 are the bandwidths associated with formants one through four, respectively. FØ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transitions from one value to another were linear with respect to time.

relative to the stressed /ra/ and /la/ syllables. Second, the values for the fundamental frequency contour rose and fell over a 2.6 semitone range (220 - 255 Hz) in a bell-shaped pattern which peaked on the middle syllable. Third, with regard to duration, the middle syllables were 270 msec. in contrast to 222 msec. for the surrounding unstressed syllables. These values for intensity, fundamental frequency, and duration are representative of values found in adult-directed speech (see Appendix C). A 1000 msec. time window was used; therefore, the minimum intersound interval was 278 msec.

Results and Discussion

As shown in Figure 7, the sucking rates of the experimental and control groups do not appear to differ significantly. Mean difference scores for the experimental and control groups were 7.78 and 8.31, respectively. Analysis of variance (see Appendix B) revealed no significant differences between the experimental and control groups for any of the pre-shift (sucking rate during the criterion minute and mean of pre-shift minutes 1 and 2) or post-shift (difference scores) response measures. Thus, the infants tested did not demonstrate discrimination of the /marana/ and /malana/ stimuli in the conditions of this experiment.

In Experiment V, infants failed to demonstrate discrimination of three-syllable sequences with adult-directed stress characteristics on the syllable of phonemic distinction. In Experiment IV, with the exaggerated correlates of stress typical of infant-directed speech, infants clearly demonstrated discrimination of the same phonemic sequences, /marana/ versus /malana/. Taken together, these results

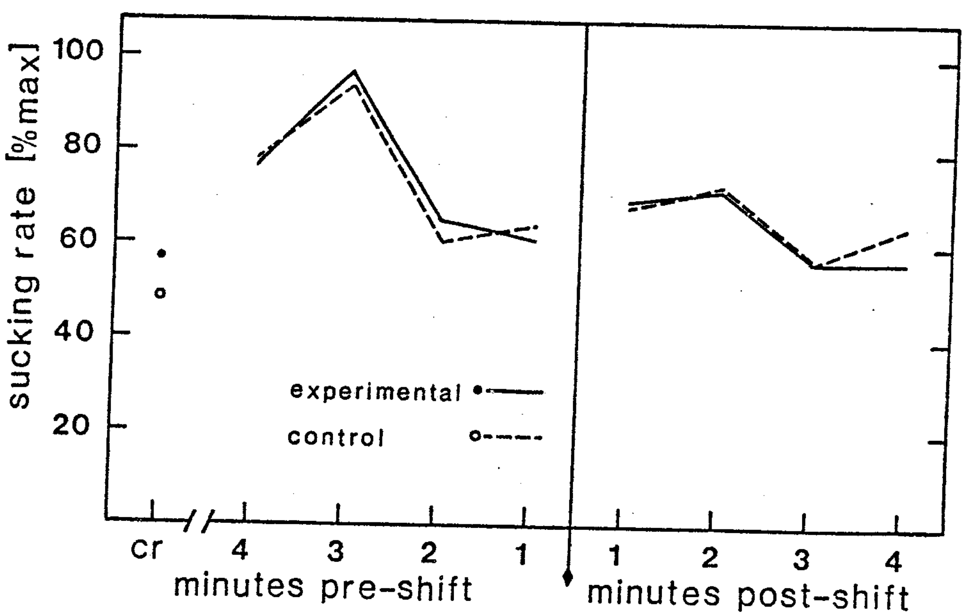

Fig. 7. Experiment V. Results of /marana/ versus /malana/. Adult-directed values for fundamental frequency, relative amplitude and duration. (CR is the criterion minute in which all infants register 20 to 35 high-amplitude sucks.)

suggest that the exaggerated suprasegmental parameters of infant-directed speech facilitated discrimination of the repeating three-syllable sequences employed in this study.

Experiment VI: Discrimination of /marana/ versus /malana/ with infant-directed stress on the initial syllable

It is clear that the infant-directed suprasegmental characteristics of Experiment IV facilitated discrimination performance with the three-syllable sequences of this study. In what way does the infant-directed stress function? Does it attract and maintain the infant's attention to the whole sequence, thereby indirectly facilitating discrimination of the middle syllables? Or does it focus attention directly on the middle syllables, highlighting the specific position of the phonemic contrast?

In Experiment VI /marana/ and /malana/ were resynthesized with infant-directed stress on the first syllable. If the infant-directed contours function to enhance the whole pattern, infants would be expected to demonstrate discrimination in this experiment.

Method

Subjects. Seventy infants were selected for this experiment and 32 (46%) completed the session satisfactorily. The 38 infants who failed to complete the experimental session satisfactorily were excluded for the following reasons: crying, N=21 (55%); sleep, N=3 (8%); failure of the sucking rate to increase during sound presentation, N=3 (8%); low pre-shift sucking rate, N=4 (11%); refusal to suck the pacifier, N=2 (5%); and experimenter error, N=5 (13%). The average age of the 16 subjects in the control group was 79.1 days (standard deviation = 12.7 days) and for the 16 subjects in the experimental group was 75.8 days (standard deviation = 12.8 days). Infant assignment rotated systematically through the four experimental conditions: 1) /marana/-/marana/; 2) /malana/-/malana/; 3) /marana/-/malana/; and 4) /malana/-/marana/. As the requisite number of infants was obtained in a particular condition, the condition was dropped from the rotation pattern.

Stimuli. For Experiment VI, the suprasegmental parameters for /marana/ and /malana/ were modeled on infant-directed speech. The initial syllable, /ma/, was synthesized according to the plan shown in Table 20. The /ra/, /la/, and /na/ syllables were the same as those synthesized for Experiment II (see Tables 9, 10, and 12), except for the fundamental frequency contours which were as shown in Table 21. Although the amplitude of voicing pattern was the same for all four syllables, later acoustic shaping reduced /ra/, /la/, and /na/ by 5 dB relative to /ma/. Thus, stimuli in this condition contained three physical correlates of stress in the initial syllable; the initial syllable was longer (400 msec. in contrast to 330 msec.), more intense (5 dB greater overall amplitude than the middle and final syllables), and higher pitched (contained the bell-shaped peak of the exaggerated intonation contour). These are the same suprasegmental characteristics that were used in Experiment IV. Since a time window of 1500 msec. was employed, the minimum intersound interval was 432 msec. for Experiment VI.

Results and Discussion

Results of Experiment VI are shown in Figure 8. Post-shift

Table 20.

Synthesis Plan for /ma/: Experiment VI

Time (msec)	FNP (Hz)	BNP (Hz)	FNZ (Hz)	BNZ (Hz)	F1 (Hz)	B1 (Hz)	F2 (Hz)	B2 (Hz)	F3 (Hz)	B3 (Hz)	F4 (Hz)	B4 (Hz)	FØ (Hz)	AV (dB)
0	280	100	520	100	550	80	1120	180	2600	50	4200	250	220	40
40														50
100													300	
105			520		550		1120	180	2600	50				
110			450		630	80	1230	70	2720	140				
135														60
140					900	190								
150			280											
170									2850	160				
180							1350							
200													350	
295														60
300													300	
400	280	100	280	100	900	190	1350	70	2850	160	4200	250	250	54

Note. The center frequency and bandwidth of the nasal pole are denoted by FNP and BNP, respectively. The center frequency and bandwidth of the nasal zero are denoted by FNZ and BNZ, respectively. F1, F2, F3, and F4 are the center frequencies and B1, B2, B3, B4 are the bandwidths associated with formants one through four, respectively. FØ is the fundamental frequency. AV is the amplitude of voicing, i.e., the relative amplitude of the glottal source. Transitions from one value to another were linear with respect to time.

Table 21.

Fundamental Frequency Values for /ra/,/la/ and /na/ : Experiment VI

Syllable	Time (msec.)				
	0	80	165	250	330
/ra/	250 Hz	230 Hz	220 Hz	210 Hz	200 Hz
/la/	250 Hz	230 Hz	220 Hz	210 Hz	200 Hz
/na/	200 Hz	195 Hz	190 Hz	185 Hz	180 Hz

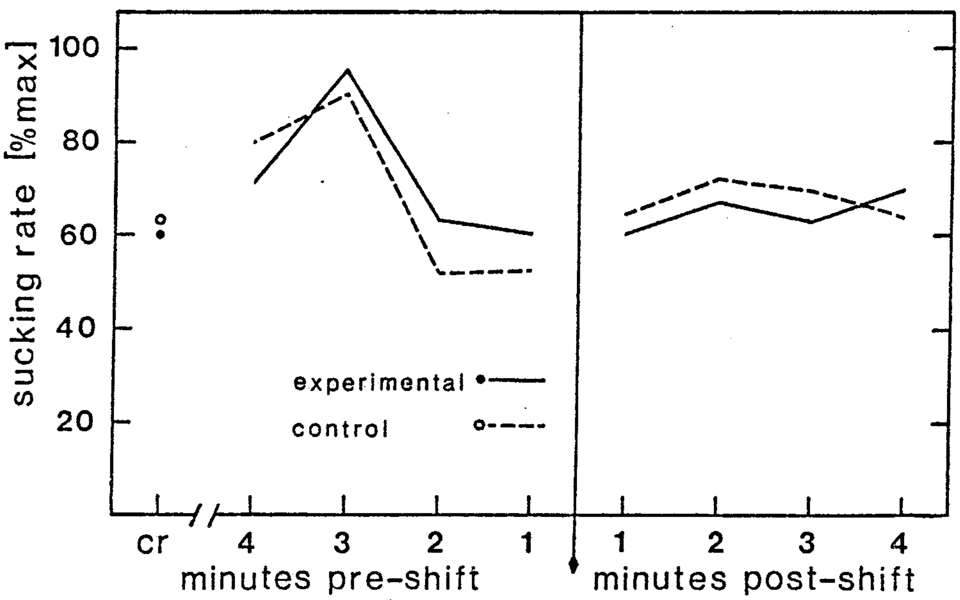

Fig. 8. Experiment VI: Results of /marana/ versus /malana/. Adult-directed values for fundamental frequency, relative amplitude, and duration. Stress is on the initial syllable. (CR is the criterion minute in which all infants register 20 to 35 high-amplitude sucks.)

sucking rates do not appear to be significantly different; indeed, the sucking rates of the control group increased more in the post-shift portion of the experiment than those of the experimental group. Mean difference scores for the experimental and control groups were 1.53 and 16.44, respectively. As shown in Appendix B, the control and experimental groups were not significantly different with respect to difference scores.

Although the experimental and control groups were not significantly different at the start of the session (i.e., criterion minute settings were not significantly different), their pattern of habituation appears to differ markedly. The difference in the means of pre-shift minutes 1 and 2 for the experimental and control groups was significant at the .05 level ($p= .0501$, $F= 4.17$, $df= 1/30$). If the experimental group had shown evidence of recovery during the post-shift phase, this difference in habituation between the groups as well as the apparent recovery of the control group would have been more worrisome; it could have masked discrimination of the experimental group. However, in this experiment the experimental group performance was devoid of significant recovery (percent increase of post-shift minute 1 and 2 relative to pre-shift 1 was -0.75%); therefore, the anomolous findings do not significantly affect interpretation of the findings. It may be concluded that the experimental group infants failed to produce evidence of discriminating /ma<u>ra</u>na/ and /ma<u>la</u>na/ in this experiment.

The infants failed to discriminate the unstressed /<u>ra</u>/ and /<u>la</u>/ syllables when they were embedded within infant-directed sequences (i.e., /<u>ma</u>rana/ and /<u>ma</u>lana/) with stress on the initial syllable.

Thus, discrimination of three-syllable sequences appears to be facilitated if 1) the suprasegmental aspects are representative of infant-directed speech, and 2) infant-directed stress characteristics are centered on the syllable to be discriminated. Based on these results, the most plausible explanation for how the infant-directed highlighting functions is that it serves to focus attention directly on the syllable to be discriminated.

Chapter 5

SUMMARY AND CONCLUSIONS

Summary of Experiments I to VI

This series of experiments was designed to investigate discrimination of the phonemic contrast /ra/ versus /la/ by young infants of 1 to 4 months of age in a variety of stimulus conditions. Eimas (1975b) found that young infants demonstrated discrimination of this contrast given synthetic sounds modeled on the characteristics of the male voice. Results of Experiment I supported the previous results of Eimas (1975b) which demonstrated that young infants discriminate /ra/ versus /la/ and extended these results to include synthetic speech based on characteristics of the female voice. Thus assured that infants are capable of distinguishing these speech sounds in single syllables, the experimenter concentrated on the ability of infants to discriminate /ra/ versus /la/ within the multisyllabic context of /marana/ versus /malana/ in the remaining five experiments.

In Experiment II, all three syllables of each of the sequences (/marana/ and /malana/) were equal with respect to duration and amplitude of voicing. The intonation contour rose and fell in a bell-shaped pattern over a 40 Hz range (180-220-180 Hz) during the 996 msec. duration of a sequence. Infants failed to provide evidence of discrimination of the sequences in this condition. This finding was expected, as Trehub (1973) obtained similar results with the naturally-spoken stimuli /ataba/ versus /atapa/.

In order to highlight the /ra/ versus /la/ contrast within the three-syllable sequences, an exaggerated intonation contour typical of infant-directed speech was employed in Experiment III. The infant-directed intonation contour, which rose and fell over a nearly one-octave range and peaked on the middle syllable, was identical for both stimulus sequences, /marana/ and /malana/. It was hypothesized that the highlighting of the middle syllable would facilitate discrimination of /marana/ versus /malana/. The expected result did not materialize and evidence of discrimination was not found. Intonation alone is apparently an insufficient aid to discrimination for young infants. Perhaps the arbitrary use of intonation alone as a cue to stress the middle syllable was inappropriate. Typically, in natural speech all three physical correlates of stress-- increases in fundamental frequency, duration, and intensity-- are concomitant.

In Experiment IV, a combination of infant-directed intonation, duration, and amplitude served to highlight the middle syllable of the /marana/ and /malana/ sequences. Intonation was identical to that used in Experiment III. The duration of the middle syllable was 400 msec. compared to 330 msec. for the initial and final syllables. The relative amplitude of the middle syllable was 5 dB greater than that of the surrounding syllables. With the stimuli described above, infants clearly demonstrated discrimination of the three-syllable sequences ($p < .01$). Thus, given the combined impact of the three suprasegmental characteristics of speech (i.e., intonation, duration, and relative amplitude) in their infant-directed form, infants discriminated sequences of three syllables which differed by only one speech sound.

The purpose of Experiment V was to assess discrimination performance for the /marana/ versus /malana/ sequences with adult-directed suprasegmental characteristics as cues for stress on the middle syllable. The duration of the middle syllable was 270 msec. compared to 222 msec. for the surrounding syllables. The relative amplitude of the middle syllable was 2 dB greater than that of the initial and final syllables. The bell-shaped intonation contour extended over a range of 2.6 semitones (220-255-220 Hz) and peaked in the middle syllable. Infants failed to provide evidence of discrimination in this experiment. In conjunction with Experiment IV, these results suggest that the suprasegmental aspects of infant-directed speech may play an important role in the processing of speech by 1- to 4-month-old infants.

Experiment VI was designed to learn more about how infant-directed speech functions to facilitate discrimination performance in 1- to 4month-old infants. The /marana/ and /malana/ sequences were resynthesized with infant-directed stress on the initial syllable. If the exaggerated intonation contour, relative amplitude, and duration serve to make the whole sequence more salient, infants would be expected to discriminate the /marana/ versus /malana/ sequences presented in this experiment. However, the infants failed to provide evidence of discrimination. Therefore, it is more probable that the exaggerated suprasegmental contours used in Experiment IV focused the attention of the infants on the distinctive middle syllable, thereby facilitating discrimination in a direct manner.

Overall Measures of Performance

During the course of the six experiments reported, 422 infants attended experimental sessions. As shown on the data form in Appendix A, many variables in addition to the sucking rates were coded at the time of the experiment. These variables included the following: subject number (1-422); age in days; sex; method of feeding (bottle, breast, or both); frequency of pacifier use (never, sometimes, often); frequency of sucking thumb or parts of the hand (never, sometimes, often); visual stimulus (geometric, woman with brown hair, woman with blond hair); assistant; experimenter; pediatrician; number of minutes to habituation; completion (satisfactory, not satisfactory); group (control or experimental); and experimental condition. Thus, many variables were accessible for analysis.

Age and Performance

With respect to the age of the infants, two aspects of performance were investigated, viz., satisfactory completion of the experiment and the magnitude of the difference score for infants in the experimental group. Behavioral observation in the present study suggested a possible inverted-U-shaped function for satisfactory completion as a function of age. It seemed that the youngest infants of approximately 35 to 56 days were often more responsive to "internal" stimulation than to the sounds presented. These young infants appeared to fuss and fall asleep more often than slightly older infants. The oldest infants of 90 to 112 days showed the most dramatic initial response to the sounds, but often became restless as presentations continued. These older infants frequently shifted their gaze and engaged in frequent hand and arm movements. Some support for the inverted-U-shaped function relating age and satisfactory completion may be seen in Figure 9, which shows that only 37% of the youngest infants of 35-45 days and 26% of the oldest infants of 101-112 days completed the experimental sessions satisfactorily. The rate of successful completion for infants of 46-100 days ranged from 43% to 52%.

Previous researchers such as Eimas et al. (1971) and Trehub and Rabinovitch (1972) did not find significant differences in performance as a function of age (within the age range tested, i.e., 1- to 4-month-old infants). Data from the present study support this finding. Correlation of magnitude of the difference score with age for infants from the experimental groups of all six experiments yielded a Pearson's r of -0.15 indicating a weak negative correlation (not significant at the .05 level) between age and difference score.

Method of Feeding and Satisfactory Completion

Throughout the course of the study mothers asked whether or not breast-fed babies were "good" subjects. As may be seen in Table 22, infants who were totally breast-fed and who had never had a pacifier completed satisfactorily only 28% of the time. Excluding this group, the overall success rate in the study ranged from 41% to 57%. Provided that the breast-fed infants had some experience with a pacifier, their completion rate fell within a similar range (46% to 52%).

Assistants

The ideal situation is to have the same assistant for all of the infants. This was not possible; throughout the course of the study

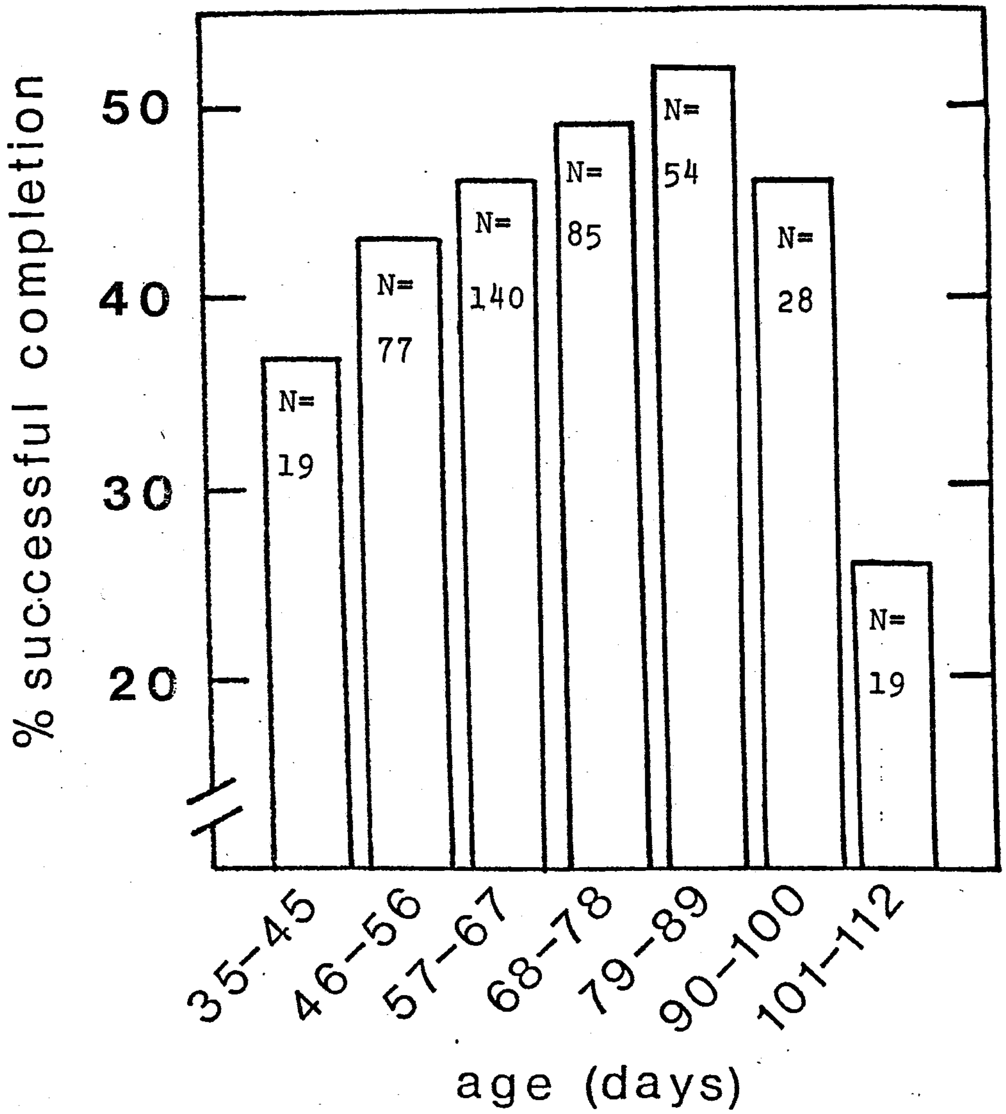

Fig. 9. Percent of infants completing satisfactorily by age category. N represents the number of subjects in each age category.

Table 22.

Percent of Infants Completing Satisfactorily by Method of Feeding

	Frequency of Pacifier Use		
Feeding Method	Never	Sometimes	Often
Bottle	50% (N=14)	46% (N=49)	41% (N=33)
Both	46% (N=10)	47% (N=27)	57% (N=16)
Breast	28% (N=9)	52% (N=24)	46% (N=10)

Mean overall rate of successful completion = 45%

seven assistants participated. Three of these assistants worked with fewer than 10 infants and their performance will not be evaluated. The rate of infants completing satisfactorily associated with the four primary assistants was as follows: assistant 1, 41% (N=91); assistant 2, 48% (N=42); assistant 3, 47% (N=163); and assistant 4, 47% (N=114). Thus, no marked differences were noted in the performance of the assistants.

Measures of Habituation

The exact cognitive and/or physiologic mechanisms responsible for habituation with infants in the high-amplitude sucking paradigm using auditory stimuli are not fully understood. Eimas et al. (1971) suggest that habituation to the repeating stimuli is presumably a "consequence of the lessening of the reinforcing properties of the initial stimulus." If habituation is dependent upon the reinforcement properties of the stimuli, then the number of high-amplitude sucks should be an appropriate index to habituation in the contingent sucking paradigm.

Kuhl (1976) suggests "that time to habituation reflects the time it takes an infant to discover that nothing new is being presented, or, said differently, the time it takes for him to learn the stimulus set" (p. 276). Kuhl and Miller (1982) found significant differences in time to habituation among the groups in their perceptual constancy study. Shorter time to habituation was found when infants were presented with single vowels; longer time to habituation occurred when two <u>different</u> vowels were presented and when two vowels with concomitant pitch changes were presented.

Taking into account both of these perspectives, one would expect infants to habituate rapidly given phonemically simple and suprasegmentally "dull" stimuli. In the present experiments it was expected that infants would produce more high-amplitude sucks during the preshift phase and take longer to habituate for Experiments IV and VI (with /marana/ and /malana/ and infant-directed intonation, relative amplitude and duration) than for Experiment I (with /ra/ and /la/ and adult-directed intonation, amplitude variation and duration). Table 23 contains the mean values of both the number of minutes and the number of high-amplitude sucks prior to the shift in stimulus for each of the six experiments. Analyses of variance revealed no significant differences among the mean values across experiments for either the number of minutes ($F = .3$, $df = 5/191$, $p = .91$) or the number of sucks ($F = .7$, $df = 5/191$, $p = .62$).

The range of 7.88 to 8.88 minutes to habituation in the present study is comparable to values found by Kuhl (1976) for infants hearing single vowels and two vowels with slightly different pitch contours. Despite changes in phonemic complexity (one versus three different syllables) and in the suprasegmental style (adult-directed versus infant-directed) across experiments in the present study, no significant differences in time to habituation were noted. Why didn't the three-syllable stimuli with infant-directed suprasegmental characteristics in the present study result in the infants taking longer to habituate? One explanation revolves around the concept of stimulus uncertainty (e.g., the greater the number of stimuli in the set and the more random the manner of presentation, the higher the level of

Table 23.

Measures of Habituation for Experiments I to VI

Experiment	Number of High-Amplitude Sucks Prior to Habituation		Number of Minutes Prior to Habituation	
	Mean	Standard Deviation	Mean	Standard Deviation
I	290.56	158.59	8.28	2.89
II	307.69	264.79	8.13	3.72
III	300.69	262.26	8.88	4.57
IV	364.97	330.89	8.72	4.88
V	334.13	305.97	8.66	4.05
VI	252.84	157.92	7.88	3.29

stimulus uncertainty). Time to habituation was significantly longer in the experiments of Kuhl (1976) when two different sounds were presented at random to the infants within one habituation period. Thus, Kuhl's experimental design was such that stimulus uncertainty was relatively high. Although only two different stimuli were presented, the infant had no way of knowing which one would be presented contingent upon a given high-amplitude suck. In the present study the stimulus uncertainty was relatively low because one stimulus was repeated consistently (often over 200 to 300 times) during the time prior to habituation. Presumably, infants would require a longer period to learn a stimulus set and would be more interested in the variety of stimulus combinations in Kuhl's (1976) experiment in which multiple stimuli were changing at random than in the present study in which only one stimulus was repeated with no variation.

In Defense of the High-Amplitude Sucking Procedure

The drawbacks of the high-amplitude sucking procedure are numerous and well-known by those who have used the procedure. First, infants may fail to demonstrate discrimination either because they lack the capacity to do so or because the post-shift stimulus is not sufficiently novel to elicit an increased rate of sucking. Second, inferences concerning the performance of individual infants are not valid; interpretation must be based on group data. Third, considerable intersubject variability exists with respect to the interval of time between the last pre-shift sound and the first post-shift sound. Thus, the memorial demands of the task differ markedly from infant to infant. Fourth, at best only about half of the subjects tested provide usable data.

Recent experiments with the head-turn technique have proved highly promising. In contrast to the high-amplitude sucking procedure, this technique allows for valid analysis of individual performance. Stimuli to be discriminated may be separated by brief intervals of time, thereby reducing the memory demands on the infants. For infants of 5-1/2 months of age or older, head-turn procedures have been used successfully. The highest rate of successful completion has been reported for infants in the range of 5-1/2 to 10 months of age (Kuhl, 1979). If the study of speech discrimination is to continue with younger infants of one to four months of age, then a sucking procedure or heart-rate technique[9] is still perforce the most appropriate method currently available.

Implications

A much-debated issue in the literature pertaining to language acquisition has been whether infants first learn the segmental or the suprasegmental aspects of speech. Traditionally, researchers have studied the segmental and suprasegmental aspects of speech separately. Studies of speech discrimination by young infants focused on either

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[9]The heart-rate technique has problems analogous to those of the high-amplitude sucking procedure. Group data are necessary for interpretation. Traditional heart-rate procedures required 20- to 30-second inter-trial intervals. The newer "no-inter-trial-interval" paradigm has brief inter-trial intervals and has been successfully used in several studies (Trehub et al., 1981). However, Trehub et al. (1981) suggests that the "modified technique still seems to pose greater demands on the infant than does the HAS [high-amplitude sucking] procedure, as evidenced by conflicting findings with these procedures when the identical stimuli are used with infants of the same age ...." (p. 23)

contrasts between speech sounds or changes in intonation, stress, and/or duration. This analytic approach has been fruitful and has yielded a considerable amount of information about the receptive speech abilities of infants. However, in undertaking the study of complex speech signals such as multisyllabic sequences, it may be necessary to part with tradition and address the issue from a new perspective. How do the suprasegmental and segmental aspects of speech interact and impact on the processing of speech by young infants?

The present study begins to address this question. The exaggerated suprasegmental characteristics of speech addressed to infants appear to play an important role in the perception of speech by young infants. The pattern of results obtained in the six experiments of this study suggests that the suprasegmentals of infant-directed speech facilitate discrimination by focusing the infant's attention on the distinctive syllable of multisyllabic sequences.

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APPENDIX A

A1 Information Sheet

A2 Consent Form (General)

A3 Consent Form (Jewish Hospital)

A5 Consent Form (Barnes Hospital)

A7 Data Form

Appendix A

CENTRAL INSTITUTE FOR THE DEAF
RESEARCH LABORATORIES
909 SOUTH TAYLOR AVENUE
SAINT LOUIS, MISSOURI 63110

Infant Research Project

What our research is about

We want to know if infants can hear the difference between certain speech sounds. For example, does "ra" sound different from "la" to babies? We also want to discover the role of pitch and stress in attaining and maintaining the attention of infants. These experiments will help us find out how babies learn language.

How we will do our research

The baby will be placed in a crib. An assistant will sit facing the baby and place a special pacifier into the baby's mouth. The pacifier is made to pick up changes in pressure, so that we can tell how fast and hard the baby sucks. If the baby sucks hard and rapidly, our sound-making equipment produces speech sounds. The harder and faster the baby sucks, the more speech sounds will be played. As the sound repeats, the baby gets used to it and should tend to suck more softly and slowly. If we then change to a new sound, the sucking should become harder and faster if the baby can tell the difference.

Each session will probably last about 40 minutes. You will be able to watch your baby on a TV monitor. Often, a baby will fall asleep or begin to cry. If this happens, the session will not be completed. If we think that your baby has not responded at all to any sounds during the session, we will recommend that a formal hearing examination be scheduled. We do not expect any harmful effects on the babies due to the testing procedure. Health and safety guidelines recommended by a pediatrician, Dr. Kathleen Winters, will be followed.

Participation Instructions

If you would like to participate or if you need more information, please call Mrs. Karzon. She may be contacted as follows:

Morning	11:00 a.m. to 12:00 p.m.	652-3200, ext. 328
Afternoon	1:00 p.m. to 4:00 p.m.	652-3200, ext. 330
Evening	7:00 p.m. to 10:00 p.m.	962-0943

All mothers and infants who attend their scheduled appointment will receive a subject fee of $3.35 or a small gift for their infant.

Appendix A

Central Institute for the Deaf

Having read the above information, I understand the nature of the experiment and agree to let my child, ______________________________,
participate as a subject. I believe the potential value of the experiment warrants any possible mild inconvenience associated with participation.

I realize that the experiment is not designed to assess the status of my child's hearing.

I understand that I have the right to withdraw my child from the experiment at any time.

______________________________ ______________________________

Date Signed

____

Relation to Subject

Appendix A

Appendix D

THE JEWISH HOSPITAL OF ST. LOUIS

Consent for Participation in Research Activities '8 1 '3

(To be used only in connection with research approved by The Jewish Hospital of St. Louis Research Committee)

Participant: ______________________ Date: __________ Time: ________ a.m. p.m.

1. I hereby authorize Dr. James Miller (CID) , and/or such assistant as may be selected by him, to perform upon me the following procedures in connection with a research project: ---

   To contact me while I am a postpartum patient at The Jewish Hospital of St. Louis and ask whether I am interested in having my infant participate in a program to determine auditory discrimination. The procedure will be explained by personnel from the Central Institute for the Deaf, and the study will be conducted at the Central Institute for the Deaf.

   (See attached.)

2. I am informed of possible benefits associated with the procedures described above. These are: ---

   If my infant fails to respond to the sounds, appropriate referral for hearing tests will be made.

3. I am informed of certain hazards and discomforts which might be associated with the procedures described above. These are: ---

   None to my knowledge.

Appendix A

3 1 3

Date: ____________________

4. I am informed that the following alternative procedures are available that may be advantageous to me: ---

   Not to enroll my infant in the study.

5. I understand that the investigator is willing to answer any inquiries I may have concerning the procedures herein described.

6. I UNDERSTAND THAT I AM FREE TO WITHDRAW MY CONSENT AND TO DISCONTINUE PARTICIPATION IN THE PROJECT OR ACTIVITY AT ANY TIME WITHOUT INTERFERING WITH SUBSEQUENT COURSE OF TREATMENT.

7. I understand that the Hospital will provide immediate medical treatment in the event that a physical injury results because of my participation in this project. I also understand that no financial compensation will be paid to me by the Hospital.

8. I HAVE READ THE ABOVE, and I HEREBY CONSENT to the performance of the above procedures upon me.

____
Participant's Signature

____
Witness

I have explained the above to the participant on the date and at the time above written.

____
Investigator's Signature

Appendix

WASHINGTON UNIVERSITY
SCHOOL OF MEDICINE

INFORMED CONSENT FOR PARTICIPATION IN RESEARCH ACTIVITIES

Participant ____________________ Date ____________________
Principal Investigator James D. Miller, Ph.D.
Human Studies Committee approval number 8107500
82-8905
Title of Project Auditory Discrimination by one- to four- month old Infants

This form is to be typewritten, clearly defining all risks and benefits in layman's language and used only in connection with research approved by the Human Studies Committee.

1. I hereby authorize Dr. James D. Miller, Ph.D. and/or such assistants as may be selected by him for use now or at a later time, to perform upon me the following procedures in connection with a research project:
(State nature of procedures, including any drugs to be administered. Identify those which are experimental.)

The baby will be placed in a crib. An assistant will sit facing the baby and place a special pacifier into the baby's mouth. Each session will probably last about 40 minutes. You will be able to watch the baby on a TV monitor. Often, a baby will fall asleep or begin to cry. If this happens, the session will not be completed.

2. I understand the possible benefits to myself or others associated with the procedures described above. These are:
(State the possible benefits.)

Knowledge of infants' ability to discriminate speech sounds in conjunction with findings on utilization of suprasegmental cues may have important implications for theories of language acquisition and may ultimately contribute to clinical test development for young infants.

3. I understand certain hazards and discomforts might be associated with the procedures described above. These are:
(Describe possible hazards and discomforts.)

The procedures does not entail any but normal infants activities.

4. I understand the following alternative procedures are available that would be advantageous to me:
(Describe alternative procedures and advantages.)

Not applicable

(continued)

Appendix A

5 I understand the the investigator is willing to answer any inquiries I may have concerning the procedures herein described. All the inquiries I have at this time have been answered. I understand the confidentiality of my records will be maintained in accordance with applicable state and federal laws.

6. I understand that my participation is voluntary and that I may refuse to participate and/or withdraw my consent and discontinue participation in the project or activity at any time without penalty or loss of benefits to which I am otherwise entitled. I also understand that I may ask a question or state a concern to the University's Chairman of the Human Studies Committee, and that the investigator will, on request, tell me how to reach the Committee Chairman.

7. I understand the the University will provide immediate medical treatment in the event that a physical injury results because of my participation in this project. I also understand that no financial compensation will be paid to me by the University.

8. To the best of my knowledge I am not pregnant, and if I do become pregnant I will notify the principal investigator of my pregnancy.

9. I have received a copy of this informed consent which I have read and understand. I hereby consent to the performance of the above procedures upon me.

____
Parent or legal guardian's signature on particticipant's behalf if participant is less than 18 years of age or not legally competent. (Blood drawing only: Less than 17 years of age)

____
Participant's Signature

____
Auditor Witness' Signature, if witness is present

I have explained the above to the participant (or parent or guardian) on the date stated on this Informed Consent for Participation in Research Activities.

____
Investigator's Signature

Appendix A

1 2 3	4	5 6 7	8	9	10	11	12	13	14	15	16	17	18
ID		AGE		SEX		FEED		PACIF		THUMB		NIPPLE	

19	20	21	22	23	24	25 26	27	28-30	31
VISUAL		ASST		EXPTER		DOCTOR		CRIT-ER	

32-34	35	36-38	39	40-42	43	44-46	47
PRE 6		PRE 5		PRE 4		PRE 3	

48-50	51	52-54	55	56-58	59	60-62	63	64-66	67	68-70	71-72
PRE 2		PRE 1		POST 1		POST 2		POST 3		POST 4	

73 74	75	76	77	78	79
RUN TIM		COMP		CORE	COND

NAME ____________________

DOB ____________________

DOT ____________________

APPENDIX B

B1 Statistical Analysis Results of Experiments I through VI

B2 Mean Sucking Scores for Experiments I through VI

Appendix B

Statistical Results of Experiments I through VI.

Groups	Pre-shift: Criterion Setting F	P	df	Pre-shift: Mean of Pre 1 + Pre 2 F	P	df	Post-shift: Difference Score F	P	df
Experimental I vs Control I	.61	.44	1/30	1.63	.21	1/30	10.99	** .002	1/30
Experimental II vs Control II	1.06	.31	1/30	1.53	.23	1/30	2.54	.12	1/30
Experimental IIIa vs Control II	.04	.85	1/30	1.62	.21	1/30	.99	.33	1/30
Experimental IIIb vs Control II	.95	.34	1/30	.07	.79	1/30	.69	.41	1/30
Experimental IIIa vs Experimental IIIb	1.20	.28	1/30	.74	.40	1/30	1.33	.72	1/30
Experimental IIIa + IIIb vs Control II + IV	2.43	.12	1/62	1.33	.25	1/62	3.07	.08	1/62
Experimental IV vs Control IV	1.46	.24	1/30	2.41	.13	1/30	8.67	** .006	1/30
Experimental V vs Control V	1.78	.19	1/30	.02	.88	1/30	.01	.94	1/30
Experimental VI	.26	.62	1/30	4.17	* .05	1/30	3.10	.09	1/30

(Response Measures)

* significance beyond the .05 level

** significance beyond .01 level

Appendix B

Mean sucking rates as percent of maximum for Experiments I, II, III, IV, V, and VI.

Minutes	Experiment											
	I		II		III		IV		V		VI	
	E	C	E	C	E	E	E	C	E	C	E	C
Criterion	60	57	59	56	55	60	51	46	57	49	61	64
Pre-shift												
min. 4	71	80	82	82	76	71	73	76	77	78	71	81
min. 3	93	86	90	92	93	94	89	95	97	94	96	91
min. 2	54	63	54	64	54	63	56	63	65	60	64	52
min. 1	55	58	57	57	54	55	53	59	61	64	61	53
Post-shift												
min. 1	77	51	65	63	58	62	79	56	70	69	61	65
min. 2	75	64	74	58	71	69	79	56	72	73	67	72
min. 3	76	55	62	65	73	61	61	63	57	57	63	70
min. 4	66	64	58	58	74	70	74	57	57	65	70	64

Legend: E- experimental group
C- control group

Note. Number of subjects in each group (column) is 16.

APPENDIX C

Values for the Acoustic Correlates of Adult-Directed Stress

C1 Duration

C2 Relative Amplitude

C3 Intonation

Appendix C

Values for the Acoustic Correlates of Adult-Directed Stress

In Experiment V the middle syllables /ra/ and /la/ within the sequences /marana/ and /malana/ were stressed in order to highlight the phonemic difference. The three primary acoustic correlates of stress in English are fundamental frequency, duration, and intensity (Fry 1955, 1958; Bolinger 1958; Morton and Jassem, 1965). These correlates of stress have been studied primarily in the context of one- or two-syllable utterances by male talkers comprised of consonants other than /r, l, m/ and /n/. Although it was difficult to extract values from the literature which would apply directly to the stimuli of this study, a brief description of the main experimental findings which influenced selection of values follows. This brief outline is not to be construed as a thorough review of the literature, but merely a rough guide which provided initial values for the trial and error process of creating usable synthetic stimuli.

Duration

Pickett (1980) analyzed the speech of an American talker saying the phrase "anticipation of downstream articulations." He reported syllable rates for different gradations of speaking rate from very slow to fast which correspond to syllable durations as follows: "very slow"-- 344 msec.; "slow"-- 323 msec.; "normal formal"-- 222 msec.; "conversational"-- 200 msec.; and "fast"-- 179 msec. Before selecting syllable durations on the basis of this listing, one must consider the fact that "the greater the number of subunits of speech in a unit of speech, the shorter is each subunit." (Lindblom et al., 1977, cited in Pickett, p.97) Since the values for the present study would apply to a three-syllable rather than a thirteen-syllable utterance, the durations suggested by Pickett (1980) would need to have slighty greater duration. Values for the adult-directed style of speech used in Experiment V ranged from 222 to 270 msec. These durations are within the range of "conversational" or "normal formal" speech.

The selection of durations for the stressed versus unstressed syllables was guided primarily by the work of Fry (1955). He suggests that changes in vowel duration rather than consonant duration are affected by a shift in stress. Analysis of vowel durations for ten words (i.e., noun and verb forms of <u>object</u>, <u>subject</u>, <u>contract</u>, <u>permit</u>, and <u>digest</u>) spoken by twelve talkers yielded durations of 110 to 190 msec. for stressed syllables and 43 to 124 msec. for unstressed syllables. Given consonant durations in the range of 80 to 150 msec. (including the transition) for /<u>m</u>, <u>n</u>, <u>l</u>/ and /<u>r</u>/, the durations of 270 msec. (stressed syllables) and 222 msec. (unstressed syllables) used in Experiment V were within the appropriate range of values.

Relative Amplitude

The work of Fry (1955) was also instrumental in the selection of values for relative amplitude. In the same study described above, he found intensity ratios for stressed versus unstressed syllables (for the stimulus <u>object</u>) ranging from +0 to +12 dB. Flanagan (1957) found that the difference limen for overall amplitude for a synthetic vowel was approximately ± 1 dB. The relative overall amplitude of the stressed syllables in Experiment V was 2 dB greater than the surrounding unstressed syllables. This value appears to be in the range produced by talkers (Fry, 1955) and well within the range of perceptible differences (Flanagan, 1957).

Intonation

Pitch is thought to be the primary cue to linguistic stress (Bolinger, 1958; Morton and Jassem, 1965). The fundamental frequency excursion applied to the three-syllable sequences in Experiment V was on the order of 2.6 semitones; i.e., there was a 16-percent change with fundamental frequency ranging from 220 to 255 Hz. The value was extrapolated from the value of 3.5 semitones/second, which is representative of the range over which adult-directed conversation varies (Fernald, 1978). This value also appears to be in agreement with the work of McClean and Tiffany (1973) which was carried out within the framework of linguistic stress analysis.

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