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ABSTRACT

INFANTS' PERCEPTION OF ACOUSTIC CUES FOR THE VOICED ALVEOLAR STOP IN TWO VOWEL ENVIRONMENTS

By

Kristine MacKain King

A critical question in infant speech perception concerns whether or not infants perceive speech linguistically. The present study investigated this question using an infant learning task and a generalization paradigm. Specifically, it was asked whether or not infants could categorize as the same two diverse acoustic cues which signal the same phone, /d/. Twelve 3-to-5 1/2 month-old infants (average age = 4.4 months) were equally divided into two experimental groups and one control group. Speech stimuli in the experimental groups consisted of the discriminative stimuli /di/ and /ga/ and the test stimulus /du/ or the discriminative stimuli /du/ and /ga/ and the test stimulus /di/. In the control group, the discriminative stimuli were /di/ and /du/ and the test stimulus was /ga/. The experiment proper consisted of two sequential stages, a conditioning phase and a test phase. During the conditioning phase, each infant was conditioned to discriminate between the two discriminative stimuli with

directional head turns. Following attainment of an a priori criterion level of correct responses, test stimuli were introduced along with the discriminative stimuli and each infant's directional generalization responses to the test stimuli were measured. Correct responses to the discriminative stimuli were reinforced; the generalization stimulus was not reinforced.

Two infants successfully responded with directional head-turns during the conditioning phase, one infant from the experimental group di/ga and one infant from the control group di/du. A third infant from the experimental group di/ga showed signs of conditioning towards the end of the test phase. Both conditioned infants' directional responses to the test stimuli during the test phase were random. The random responses of the control subject were expected for the control condition. The experimental subject's random responses, however, did not support the linguistic hypothesis. The perceptual saliency of the steady-state vowel and its possible role dominance in making generalization responses was offered as a possible explanation for failure to support the linguistic hypothesis.

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INTRODUCTION

Studies of infant speech perception indicate that young infants can discriminate differences in speech sounds. For example, infants can discriminate pairs of speech stimuli that differ in voice, place of articulation, and manner of articulation for consonants or that differ in tongue height and/or point of maximum constriction for vowels. There are at least two possible explanations for the infant's ability to make these perceptual discriminations. First, the infant may be coding speech auditorily and discriminating differences on the basis of auditory features extracted from the speech signal. Second, the infant may be coding speech linguistically and discriminating differences on the basis of extracted linguistic features from the speech event.

Several investigators have tested the first explanation that infants code speech linguistically (e.g., Cutting and Eimas, 1974; Eimas, Siqueland, Jusczyk and Vigorito, 1971; Morse, 1972). Although these studies suggest that infants perceive speech in a linguistic mode, serious methodological problems preclude a clear interpretation of their results.

The purpose of the present study was to determine whether young infants perceive speech linguistically or auditorily. Operantly conditioned head turning was used to shape the initial perceptual discrimination. Then, a generalization task was used to test the linguistic versus auditory processing hypotheses. Specifically, this study investigated infants' ability to equate two diverse acoustic cues which signal the same phone.

LITERATURE REVIEW

The literature review is divided into three major sections: the need for a linguistic code in speech perception, evidence (from adults) which supports linguistic coding in speech perception and auditory coding in non-speech sounds, and evidence which supports linguistic coding in the perception of speech by infants.

The Need for a Linguistic Code

This section is designed to demonstrate the reasons why the acoustic signal of speech has to be coded in order for it to be perceived as speech and the conditions under which speech is coded by infants if they, in fact, perceive speech linguistically. Specifically discussed are 1) the discrepancy between the acoustic speech signal and its final representation as a linguistic event and 2) the subsequent need for a transformation of speech sound into speech phone, enabling speech to be segmented into a sequence of phonemes. Further, it is suggested that if infants code speech linguistically, they must be capable of coding discrepant acoustic cues in the speech event as the same phone.

In most cases of speech perception, there is no way to map the acoustic signal directly onto a sequence of

phones such that any given acoustic segment will correspond to a given phone. Speech perception is therefore considered a complex process which requires that the acoustic signal be decoded through some type of an analysis-by-synthesis procedure in order for it to be perceived as speech (Liberman, 1970; Stevens & Halle, 1967).

As an example of the complexity of speech, the same acoustic segment may provide simultaneous cues for the perception of two distinct phones. For example, the second formant transition which connects the consonant [C] and vowel [V] in a CV or VC sequence provides simultaneous information about place of articulation for the consonant and the identity of the vowel. In fact, at no point along the formant transition can the consonant be segmented from the vowel so that the two phones are perceived separately (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). Interestingly, different acoustic events contain information that signal the same phone, requiring a temporal synthesis of cues for accurate phoneme perception (Mattingly & Liberman, 1969). For example, in some CV sequences identification of a specific stop consonant requires information provided by both the initial consonant burst and the second formant transition connecting the consonant and vowel. Therefore, perception of continuous speech requires simultaneous processing of cues for different phones and temporal synthesis of cues for the same phone.

To add to the complexity of the speech (or linguistic) code, the same acoustic cue may signal the perception of two distinct phones, depending upon its syllabic environment. To illustrate, Liberman, Dellatre, & Cooper (1952) found that an 1800 Hz noise burst was perceived as /p/ when it preceded /u/ or /i/ and as /k/ when the burst occurred before /a/. Conversely, the same phone may be signalled by two different acoustic cues depending upon its syllabic environment. For example, the second formant transition signalling the perception of /d/ rises when /d/ is followed by /i/ and falls when /d/ is followed by /u/ (Liberman et al., 1967). In this example, then, perception of /d/ requires the transformation of a variable acoustic cue into the same linguistic event, /d/. If infants are perceiving speech linguistically, they must transform these cues into the same phone. However, if they are perceiving speech auditorily, the transformation of sound into phone does not take place and the two acoustic cues will be perceived as different auditory events. This perceptual dichotomy provides a sensitive test for whether or not infants are coding speech linguistically or auditorily and serves as the basis for testing the hypothesis advanced in the present study.

Differences Between Speech Perception and Auditory Perception

The purpose of reviewing several studies concerned with adult speech perception is to provide experimental

evidence for the contention that speech is perceived in a linguistic mode and other auditory events (classified under the general heading, "nonspeech") are perceived in an auditory mode. First, a model of speech and nonspeech processing is presented which provides the framework for conceptualizing the way in which speech and nonspeech are perceived. Following this discussion, selected research is reviewed which experimentally demonstrates that speech and nonspeech are differentially processed and which directly or indirectly supports the differential processing model of speech perception. Support for the differential processing model comes from 1) behavioral and physiological evidence on hemispheric specialization for speech, 2) evidence from the perception of acoustic cues for speech in and out of a speech context, and 3) dichotic listening tasks.

Ample evidence exists to support the contention that speech and nonspeech sounds are processed differently (e.g., Cutting, 1974; Mattingly, Liberman, Syrdal, & Hawles, 1971; Studdert-Kennedy, Shankweiler, & Pisoni, 1972; Wood, 1973). Theoretical accounts of speech perception explain speech processing in terms of different levels or stages of processing (Day & Wood, 1972a, 1972b; Studdert-Kennedy et al., 1972; Studdert-Kennedy & Shankweiler, 1970; Wood, 1973). Specifically, speech perception involves the processing of both auditory and phonetic information as represented by the hierarchical arrangement of auditory and phonetic stages

of processing. At the auditory level, processing is accomplished by the auditory system by which extracted auditory features from the acoustic signal are converted into psychological attributes of pitch, loudness, duration, and timbre (Studdert-Kennedy et al., 1972). Based upon this auditory analysis, phonetic processing transforms the acoustic parameters of the speech signal into phones through the extraction of linguistic features. Acoustic cues extracted from the speech signal or other sounds (both classified as nonspeech) are processed at the auditory level only. The resulting distinction between speech and nonspeech perception is that speech is perceived linguistically (or phonetically) and nonspeech is perceived auditorily.

The differential processing of speech and nonspeech is substantiated both behaviorally and physiologically by studies that demonstrate hemispheric specialization for speech. Several studies have shown a right ear advantage (left hemisphere representation) for speech stimuli and a left ear advantage (right hemisphere representation) for nonspeech stimuli (e.g., Kimura, 1961, 1964, 1967). Moreover, this differential ear advantage is determined not by the stimuli themselves but by whether or not the stimuli signal linguistic or nonlinguistic attributes. Dichotic tasks using the same speech stimuli (e.g., /ba/) show a right ear advantage if the subject is asked to identify a linguistic parameter of the signal (e.g., a stop consonant)

and a left ear advantage if the subject is identifying a nonlinguistic parameter of the signal such as pitch (Day, Cutting & Copeland, 1971; Day & Wood, 1971). Using the same type of identification paradigm, Wood, Goff, & Day (1971) found significantly greater auditory evoked potentials over the right hemisphere during the nonlinguistic task. Wood and his associates used the linguistic vs. nonlinguistic task in order to clarify the results of other studies measuring auditory evoked responses to speech vs. nonspeech stimuli. These studies (specifically, Cohen, 1971; Matsumiya, Tagiliaso, Lombroso, & Goodglass, 1972; Morrell & Salamy, 1971) also demonstrated hemispheric specialization for speech vs. nonspeech stimuli.

It can be concluded from the results of these studies that speech and nonspeech are processed differently. Specifically, the linguistic aspects of speech are processed by the left hemisphere, whereas nonspeech or the nonlinguistic aspects of speech are processed by the right hemisphere.

That the perception of speech is in some sense different from the perception of other auditory events is further substantiated by studies concerned with the perception of acoustic cues for speech in and out of a speech context.

First, the acoustic cue for place of articulation for stops--the second formant transition (F2)--sounds different in and out of speech. In speech, the cue is heard as a linguistic event, for example, [bae]. When presented alone out of the speech context, however, it is heard as a chirp

of a specified frequency or as a rising glissando (Mattingly et al., 1971). Second, the acoustic cue for place is discriminated differently, depending upon whether it is in a speech or a nonspeech context. For example, Mattingly et al. (1971) demonstrated that when the direction and extent of the F2 transition in a speech context were varied by equal acoustic increments, the listener continued to hear the same stop consonant until the increment crossed the phoneme boundary. At this point, the listener heard a different stop (differentiated by place of articulation). Changes in the acoustic signal resulted in identification of either one stop or another; intraphonemic variations were not heard. In other words, perception of the acoustic cue for place in a speech context was categorical. However, when the acoustic variants were presented alone for discrimination, discrimination responses were distributed bimodally. That is, performance was either better or worse than in the speech context.

Similar results have been found with the discrimination of voice onset time (VOT), the acoustic cue which differentiates voiced and voiceless stops. VOT is defined as the interval between the release burst of the consonant and the onset of vocal fold vibration. When this dimension was systematically varied by equal increments in a speech context, perception was nearly categorical; that is, few sounds could be discriminated better than they could be identified, with speech discrimination functions

showing high peaks at the phonetic boundaries (Liberman, Harris, Kinney & Lane, 1961). However, when the cues were extracted and presented alone for discrimination out of speech, no peaks occurred at the boundaries and discrimination performance was at near chance levels.

It should be noted that these results (Mattingly et al., 1971; Liberman et al., 1961) are not meant to imply that only speech is perceived categorically. For example, Cutting and Rosner (1974) have demonstrated categorical perception of nonspeech sounds (sawtooth waves) that vary in rise time (rise time is defined as the time between sound onset and the point at which the sound reaches its maximum intensity). Thus, the same acoustic dimension (e.g., VOT or changes in the extent and direction of the F2 transition) is perceived differently in and out of speech. This is an important distinction since Liberman and his associates have argued elsewhere (e.g., Liberman, 1970; Liberman et al., 1967; Mattingly & Liberman, 1969) that categorical perception is an attribute unique to speech perception.

The perception of acoustic cues for speech that vary as a function of phonetic context are also perceived differently in and out of speech. In some CV or VC sequences, the cue for place of articulation (the F2 transition) varies as a function of the preceding or following vowel. In the /di/-/du/ example, the F2 transition signalling perception of /d/ rises in /di/ and falls in /du/. In

speech the /d/'s perceptually are identical. However, in isolation they are perceived as a rising or falling glissando or as chirps of a higher and lower frequency (Liberman et al., 1967).

It seems clear that acoustic cues for speech are processed differently, depending upon whether or not they are in a speech context (Liberman et al., 1961; Liberman et al., 1967; Mattingly et al., 1971). Out of speech the acoustic cues are perceived as auditory events and can be discriminated along a continuum. In speech, the cues are perceived as phonemes and can be discriminated no better than they can be identified. In other words, perception of the acoustic cue for speech in a speech context is categorical, or linguistic. Out of speech, perception is continuous, or auditory.

Dichotic listening tasks have provided a sensitive test for determining whether speech discriminations are based upon an auditory or linguistic feature analysis. In the tasks to be discussed, listeners identified CVC sequences where the auditory or linguistic parameters of the speech signal were experimentally manipulated. The general pattern to emerge suggests that phonemic decisions are based upon a linguistic (rather than an auditory) feature analysis.

In two studies (Hawles, 1969; Studdert-Kennedy and Shankweiler, 1970) listeners' errors were recorded to dichotically presented CVC sequences in which the stop

consonant in each pair was differentiated by two linguistic features (e.g., place and voicing). The presentation of /pa/, for example, to the right ear and /ga/ to the left resulted in responses of either /ba/ or /ka/. A response of /ba/ can be explained by the extraction and integration of voicing from the left ear and place from the right whereas /ka/ resulted from the integration of voicing from the right ear and place from the left. Responses which involved no integration of feature cues (such as /da/ or /ta/) rarely occurred. These data support the notion that linguistic features are psychologically real and further demonstrate that linguistic features can be extracted from phones and combined to form a "new" phone not presented in the original stimulus pair. Although these studies suggest that speech perception is based upon extracted linguistic (rather than auditory) features, the auditory parameters of the speech signal were not manipulated. No distinction can be made, therefore, between an auditory vs. linguistic feature dependency during speech perception.

The question of whether speech perception is linguistically or auditorily based was specifically addressed in an investigation where both parameters were experimentally manipulated (Studdert-Kennedy et al., 1972). Correct responses to dichotically presented CV pairs whose stop consonants shared both phonetic and auditory information (e.g., same place of articulation and identical F2

transitions as in /di/, /ti/) were compared with pairs which shared only phonetic information (e.g., same place of articulation but diverse F2 transitions as in /di/, /tu/). Studdert-Kennedy et al. hypothesized that if (linguistic) feature sharing (e.g., same place of articulation) is auditorily based, listeners should respond with greater accuracy to pairs which shared the same linguistic feature and identical F2 transitions. However, if speech processing is linguistically based, no difference in performance between the two stimulus sets should result. Results showed no significant difference in performance between the two sets of stimulus pairs, supporting the authors' contention that phonemic decisions are based upon the extraction of linguistic (rather than auditory) features from the speech event.

Collectively, the studies reviewed in this section indicate that 1) speech and nonspeech (or the linguistic and nonlinguistic aspects of speech) are processed in different hemispheres of the brain, 2) the acoustic cues for speech are perceived categorically in speech and non-categorically when extracted out of speech, and 3) phonemic decisions in speech are based upon a linguistic, rather than an auditory, code.

Infant Discrimination of Speech Contrasts

A number of studies have demonstrated that infants can discriminate between a variety of speech contrasts.

For example, infants have discriminated pairs of speech stimuli that are differentiated by voicing (Eimas et al., 1971; Trehub and Rabinovitch, 1972; Trehub, 1973; Eimas, 1974), place of articulation (Moffitt, 1971; Morse, 1972; Cutting and Eimas, 1974; Eimas, 1974) and manner of articulation (Eilers and Minifie, 1975) for consonants, and pairs that are differentiated by tongue height and/or point of maximum constriction of the tongue for vowels (Trehub, 1973).

Few of these studies, however, have addressed themselves to the question of whether or not the infant is coding speech linguistically. Since this hypothesis is the focal point of the present investigation, only those studies which attempt to answer the linguistic coding hypothesis will be critically reviewed. These studies can be grouped into the following general categories: 1) discrimination of the acoustic cue for voicing in stop consonants, 2) discrimination of the acoustic cue for place of articulation in stop consonants, and 3) similarity responses to two different acoustic cues which signal the same stop consonant. One other line of research will be discussed since it provides indirect evidence for linguistic processing of speech, namely the study of auditory evoked responses to speech and nonspeech stimuli.

Infant Discrimination of the
Acoustic Cue for Voicing

The purpose of the following studies was to determine whether infants perceive the acoustic cue for voicing in stop consonants in a categorical manner. Specifically, when the acoustic cue for voicing--voice-onset time (VOT)--is systematically varied in equal acoustic increments, will infants discriminate the change when it crosses the phonemic boundary but not discriminate the same increment when it occurs within a phonemic class? If infants successfully discriminate between phonemic categories but do not make intraphonemic distinctions, their performance would match that of adults'; that is, they would discriminate differences in phones no better than they could assign them to one phonemic category or another.

The results of most of the studies reviewed here suggest that infants are coding speech linguistically; however, the results cannot be clearly interpreted because of methodological problems in the discrimination paradigms employed and confounding variables inherent in the stimulus dimensions studied.

Eimas et al. (1971) were the first to investigate linguistic discrimination of speech contrasts in young infants. Their procedures have served as the basic methodology used in most subsequent investigations of infants' discrimination of speech sounds.

Eimas et al. (1971) sought to determine whether one- to four-month-old infants could perceive the acoustic cue for the voicing distinction in stops, voice-onset time (VOT), in a categorical fashion. Discrimination functions were obtained both within and between phonemic categories for /ba/ and /pa/. Each of three experimental conditions involved discrimination of a 20 msec increment in VOT. For the two within-category shift conditions, these values were -20 and 0 msec VOT (both perceived by adults as [ba]), and +60 and +80 msec VOT (both perceived by adults as [pa]). The between-category shift condition included VOT values of +20 and +40 msec VOT, both perceived by adults as [ba] and [pa], respectively. In the control (no-shift) condition, subjects heard one of the six experimental stimuli throughout the entire session.

Discrimination responses were measured using a high-amplitude sucking (HAS) procedure similar to that described by Siqueland and DeLucia (1969). First, a baseline level of high-amplitude sucking is obtained (approximately 20-30 responses/minute at a specified amplitude) under conditions of no auditory stimulation. Following baseline stimulus presentation is made contingent upon the infants' rate of sucking. Initially, the infant increases his rate of sucking in response to the (presumably) reinforcing properties of the stimulus. After a time the infant satiates to the stimulus and his sucking rate decreases. When a predetermined response decrement criterion is

reached, a new stimulus is presented. If sucking rate increases it is assumed that the infant has discriminated the stimulus. Significant group effects are computed by determining whether or not there is a significant difference between the mean sucking rate of the experimental group who have been shifted to a new stimulus and the mean sucking rate of a control group who continue to hear the same stimulus. If there is a significant difference in the rate of responding between the experimental and control groups during this period, it can be inferred that the experimental group discriminated the stimulus change.

In subsequent studies investigating the linguistic coding hypothesis, the Eimas et al. (1971) procedure was modified by making the presentation of the stimulus contingent upon the emission of each high-amplitude sucking response.

In the Eimas et al. (1971) study, there was a significant difference between experimental and control groups for the between-category shift only, allowing the authors to infer that the infants were perceiving the cues categorically, or according to phonemic categories.

Subsequently, Eimas (1975) investigated two- to three-month-old infants' categorical perception of the voiced-voiceless distinction in alveolar stop consonants. The same general procedure was employed as in the Eimas et al. (1971) study except that stimulus presentation was made contingent upon the emission of each sucking

response. Infants' ability to discriminate 50 msec variations in VOT was investigated both within and between the phonemic categories, /d/ and /t/. Again, infants demonstrated discrimination between phonemic categories but did not evidence discrimination for within-category changes.

In addition to the voiced-voiceless distinction found in English, Eimas (1975) investigated perception of a third voicing distinction, prevoicing, found in languages such as Thai. When a stop consonant is prevoiced, laryngeal vibration begins considerably before the consonant is released. In this study, two- to three-month-old infants' discrimination of 80 msec changes in VOT was investigated within the prevoiced phonemic category (which had VOT values of -70 and -150 msec) and across the phonetic boundary separating prevoiced from voiced stop consonants (with VOT values of -70 and +10 msec, respectively). No significant difference in performance was found between the within-category and between-category groups, although the between-category group did show a reliable recovery in sucking response from preshift to postshift stages.

These studies suggest that infants discriminate differences along the VOT continuum for the voiced-voiceless distinction in bilabial and alveolar stops; however, whether or not infants can discriminate differences across the prevoiced-voiced boundary is still unclear.

Two salient criticisms have emerged from studies investigating infants' discrimination of voicing contrasts

and from infant speech discrimination studies utilizing the HAS procedure. One criticism concerns questions regarding the validity of the HAS procedure. The other questions whether the speech stimuli in the voice discrimination studies can be used as a measure of linguistic discrimination of speech contrasts.

As was mentioned earlier, the methodology employed in all infant discrimination studies which test the linguistic coding hypothesis is a variation of the high-amplitude sucking procedure described by Siqueland and DeLucia (1969). The high-amplitude (HAS) procedure assumes that the infant will increase his rate of sucking above a baseline level 1) when he learns that it is his HAS response which determines stimulus presentation and 2) if he finds the stimulus event reinforcing. When the stimulus event is no longer reinforcing, the infant's sucking rate decreases. After sucking rate has decreased to a predetermined criterion, a new stimulus is presented contingent upon the infant's sucking response. Given that the infant both discriminates the new stimulus and finds it reinforcing, a subsequent increase in sucking rate will result. If the experimental group demonstrates a significant increase in recovery of HAS following stimulus shift as compared with a control group (who receive the same stimulus throughout the experimental session), it is inferred that the experimental group detected a difference between the two stimuli.

Butterfield and Cairns (1974) have challenged the rationale(s) underlying the pre- and postshift phases of the HAS procedure. Their criticisms revolve around the fact that infant speech discrimination studies have not provided adequate controls for effects which violate the assumptions underlying this procedure. The need for such controls is demonstrated in the following discussion.

During the preshift phase of the HAS procedure, an increase in sucking relative to baserate is assumed to result from the reinforcing properties of the novel stimulus. This increase continues until the minute just prior to the response decrement criterion. Butterfield and Cairns argue that whether or not the initial stimulus actually has reinforcing properties is not demonstrated using this procedure. As evidence for their position, they experimentally demonstrated that infants reliably increase their sucking rate above baseline during the minute immediately preceding a response decrement criterion, regardless of whether or not they are being presented with a stimulus. Further, the decrement in response rate following repeated presentation of the auditory stimulus cannot be attributed to a loss in the reinforcing properties of the stimulus since the same effect is experimentally produced with no contingent stimulation. Controlling for these possible effects necessitates the inclusion of two additional control groups, one group which receives no auditory stimulation and another group which receives

noncontingent auditory stimulation. To date, infant speech discrimination studies have not provided controls for these effects.

Using a random walk procedure, Butterfield & Cairns demonstrated that infants show response decrement and a subsequent increase in sucking rate by chance alone and that this function closely parallels that obtained by the experimental shift groups. This suggests that the pattern of results shown by the shift group could be occurring as a random event and not as the result of discrimination. Butterfield & Cairns, however, did not produce a random walk for the control condition. Unless a random effect can also be demonstrated under conditions of no-shift, their argument is unsubstantiated.

In summary, a causal relationship between the presentation of a stimulus and the pattern of sucking responses using the HAS procedure cannot be established 1) until adequate controls are included in experimentation and 2) until differences between experimental and control groups can be demonstrated as nonsignificant.

A criticism that has specifically arisen from studies investigating the categorical perception of VOT concerns the basis from which the discriminations are being made. The critical question, of course, is whether infants are perceiving speech auditorily or linguistically. Because categorical discrimination of VOT in stop consonants was demonstrated, Eimas and his coworkers have inferred that

infants are perceiving these distinctions according to linguistic categories.

Recently, Stevens & Klatt (1974) have offered an alternative explanation to linguistic discrimination of these specific contrasts. They suggest that infants may be making categorical discriminations on the basis of an auditory (rather than a linguistic) feature analysis; specifically, on the basis of whether or not a first formant (F1) transition occurs in the acoustic speech signal.

Stevens and Klatt isolated two important cues for perception of the voiced-voiceless distinction, voice-onset time (VOT) and the presence or absence of a significant F1 transition. The F1 transition prevails immediately following voice onset for voiced stops and is nonexistent during production of voiceless stops. This transition occurs as the result of the supraglottal articulators changing positions from the consonant to the following vowel after voice onset. During production of a voiceless stop, the articulators have already reached their target position by the time that voicing begins, and so no F1 transition results. This effect occurs for all stop consonant pairs differentiated by voicing.

In an experiment where VOT and rate of formant motion were independently manipulated, it was found that the presence of an F1 transition after voice onset was necessary for perception of a voiced stop (/d/) and that the absence

of such a transition cued perception of /t/. Stevens and Klatt concluded that the voiced-voiceless distinction in stops is categorically perceived, but according to auditory features rather than linguistic features. In their explanation, VOT values of less than 20 msec are accompanied by an F1 transition and the stop is perceived as voiced. VOT's greater than 20 msec are accompanied by no such transition and are perceived as voiceless. Although this strategy for perception of the voicing distinction in stops was specifically applied as an alternative explanation to the Eimas et al. (1971) results (which used the stimuli /b/-/p/ with a phonetic boundary of about 20 msec VOT), the F1 transition vs. no F1 transition is a characteristic of all stops differentiated by ± voice and can therefore be applied to all subsequent experiments investigating the categorical discrimination of the voiced-voiceless distinction in stop consonants.

Although Stevens and Klatt introduced an alternative explanation for the categorical discrimination of VOT in stop consonants, the strategy used by infants in making this discrimination is still unclear. Two possible alternatives still remain: auditory or linguistic.

Support for the notion that categorical discrimination of the voicing distinction can be made on the basis of auditory features alone has been provided by Kuhl and Miller (1975) in a speech perception experiment with chinchillas. Chinchillas were selected because their

auditory system resembles that of the human. The chinchillas successfully discriminated the voiced-voiceless distinction in alveolar plosives in initial position when the sequences were repeated by the same talker or by different talkers and when the tokens were repeated by the same talker and by different talkers in different vowel environments. However, the most important outcome of this experiment concerns the perception of acoustic variations in VOT of synthetically produced alveolar plosives. The discrimination function which resulted was nearly identical to that obtained from infant and adult subjects. That is, discrimination of the acoustic cue for the voicing distinction in the alveolar stops, /d/ and /t/, was nearly categorical.

The results of Stevens and Klatt (1974) and Kuhl and Miller (1975) suggest an interesting alternative to the categorical perception of stop consonants that are differentiated by voicing--that is, the phonetic boundary separating these two phonemic categories into voiced vs. voiceless stops may be the surface manifestation of an underlying acoustic distinction. If this is true, then the speech events are coded auditorily and the accurate perception of this "linguistic" distinction rests upon the auditory system's ability to resolve these differences.

Infant Discrimination of the Acoustic
Cue for Place of Articulation

The purpose of most investigations of infants' perception of the primary acoustic cue for place of articulation in stops--the second formant transition--has been to demonstrate that infants are processing the cue linguistically. Two types of evidence support a linguistic processing interpretation; 1) infants' categorical perception of the acoustic cue for place of articulation and 2) infants' differential processing of the acoustic cue for place of articulation in and out of a speech context. In each case, however, the results are inconclusive. First, infants' categorical discrimination of the place distinction can be explained in terms of auditory processing of the acoustic cues. Second, the demonstration that infants process acoustic cues for speech differently when they are a part of speech still does not directly answer the question that they are processing these cues linguistically. The second result is further weakened by the fact that not all investigators have found a clear demonstration of differential processing of speech in infants.

Morse (1972) was the first to investigate infants' linguistic perception of the place distinction in stops. Using the nonnutritive sucking procedure, he investigated two month olds' discrimination of the second (F2) and third (F3) formant transitions (which signal perception of /ba/ and /ga/) in a speech context and in isolation.

In [ba], the F2 and F3 transitions rise to the steady state vowel. In [ga], the F2 transition falls while the F3 transition rises. The experimental procedure was similar to that employed by Eimas, et al. (1971). In the speech condition, results showed a reliable recovery of sucking in the experimental group relative to that of a control group. However, in the nonspeech condition the results were bimodally distributed. That is, some infants in the experimental nonspeech group significantly increased their rate of sucking during postshift relative to postshift performance of the experimental speech group whereas others in the experimental nonspeech group either showed no change or significantly decreased their sucking relative to the experimental speech group. Because of this distribution, the results could not be clearly interpreted.

In the speech condition, there was strong evidence of discrimination between [ba] and [ga]; however, nothing can be said with respect to whether or not the discrimination was made on the basis of auditory or linguistic features since the acoustic parameters were not systematically varied.

Eimas (1975) attempted to clarify these findings by investigating categorical perception of place cues in two- to three-month-old infants. The stimuli, /dæ/ and /gæ/, were synthetically produced. The starting frequency and direction of the F2 and F3 transitions were systematically varied in equal increments, resulting in

two tokens of [dæ] and one of [gæ]. (Adults perceive the acoustic distinctions when they cross the phonetic boundary but intraphonemic discrimination are only slightly above chance levels.) Results showed discrimination of the acoustic increment when it crossed the phoneme boundary and no discrimination of within-category differences.

A similar experiment (Cutting & Eimas, 1974) was conducted employing the stimuli [bæ] and [dæ]. These two stimuli differ in the direction and extent of the F2 transition. In [bæ] there is a sharp increase in frequency from approximately 1200-1600 Hz, whereas in [dæ] there is virtually no change in the F2 transition from its starting frequency to the steady-state vowel. Six stimuli were constructed which varied by equal acoustic increments in the trajectory of the F2 transition. Four of these stimuli signalled the sequence [bæ], whereas two were perceived as [dæ]. Two- to three-month-old infants' ability to discriminate the acoustic changes within and across phoneme boundaries was investigated. Again, infants discriminated pairs where each stimulus lay across phoneme boundaries but intraphonemic variations were not detected.

The results of these studies concerning the categorical perception of place cues (i.e., Eimas, 1975; Cutting & Eimas, 1974) cannot be interpreted as evidence for linguistic processing of the acoustic cues for place of

articulation. However, an alternative explanation is available, one which explains the discrimination function in terms of auditory processing. For example, Cutting & Eimas (1974) noted that the phoneme boundary separating the linguistic categories /dæ/ and /bæ/ also serves as the boundary separating two distinct acoustic categories. For [bae], each acoustic increment involves a sharp rise in frequency from its beginning to the steady-state level of the vowel. In contrast, the two acoustic increments signalling perception of [dæ] both involve very little or no transition to the steady-state level. Given these two conditions, it is possible to categorize the acoustic increments on the basis of extracted auditory features, specifically, a sharp frequency change vs. no frequency change. Since these two distinctions fall across the natural phoneme boundary, this boundary may be the result of auditory rather than linguistic processing of the acoustic cues. The same explanation can account for the discrimination of acoustic changes for [gæ] and [dæ] (Eimas, 1975) except that in this case, the acoustic increments within the [gæ] category are signalled by a sharp fall in frequency.

Cutting and Eimas (1974) examined this possibility by extracting the F2 transition from each stimulus item (the [bæ] and [dæ] stimuli) and presenting F2 pairs for discrimination. In the nonspeech context, infants successfully discriminated each pair of nonspeech stimuli. These

results are similar to those found by Mattingly et al. (1971) with adults. That is, out of a speech context, intraphonemic variations as represented by equal acoustic increments along an acoustic continuum can be discriminated from one another until the increment crosses the phoneme boundary. Although these data represent the strongest evidence for perception in a linguistic mode, they are clouded by the equivocal findings presented by Morse (1972).

Infants' Categorization of Phones

Using a discrimination paradigm in the study of categorical speech perception introduces the possibility that discriminations will be performed successfully on the basis of cues other than the ones under investigation. All infant discrimination studies thus far reviewed are subject to this problem. My critical review of these studies has suggested that the phonetic boundary separating stop consonants into two distinct categories (on the basis of voicing or place distinctions) may in fact be a manifestation of an underlying auditory boundary. Thus, categorical discrimination of speech in infancy may be the result of auditory rather than linguistic processing.

Another way of approaching the question of whether or not the infant perceives speech linguistically or auditorily is to measure his responses to sounds which are perceptually identical (i.e., share the same phoneme) but

where each sound is cued by very different acoustic characteristics. If the infant responds in a similar manner when he hears two phones which are phonetically identical but acoustically distinct, it may be inferred that he is responding to the linguistic (rather than the auditory) features of the two sounds.

This approach was undertaken in an investigation by Fodor, Garrett, & Brill (1975) with fourteen- to eighteen-week-old infants. An attempt to condition head-turning to reinforced and unreinforced monosyllabic sequences was undertaken under the following conditions: 1) where the two reinforced monosyllables were acoustically distinct but phonetically identical (e.g., /pu/, /pi/) and a third nonreinforced sequence differed both phonetically and acoustically (e.g., /ka/) and 2) where the two reinforced monosyllables were acoustically and phonetically distinct (e.g., /ka/ and /pi/) and a third unreinforced monosyllable shared a phone present in one of the reinforced sequences (e.g., /pu/). Results suggested that the infants were responding to the phonemic identity of the two phones in the same phone group in that significantly more responses occurred under the reinforcement condition when the CV sequences shared the same initial consonant than when they did not. However, when the three experimental conditions are examined separately, one condition (/pi-ka-pu/) showed a significant effect of reinforced over nonreinforced syllables for both the same and different phones conditions.

Although Fodor et al. dismiss this result as being the consequence of a small sample size, it still weakens the support found for their hypothesis.

Molfese (1972) measured auditory evoked responses to sets of speech and nonspeech stimuli in infants, children, and adults. Speech stimuli were natural tokens of [ba] and [dæ] and naturally produced [baɪ] and [dɔɪ]. Nonspeech stimuli consisted of a piano chord and a speech noise burst containing frequencies between 250 and 4000 Hz. Significantly greater auditory evoked responses over the left hemisphere occurred for all speech stimuli in each age group. In addition, there were significantly greater auditory evoked responses over the right hemisphere in each group for the nonspeech stimuli. Although these data do not relate directly to the phonemic coding capabilities of the young infant, they do suggest that speech lateralization is present very early in infancy. Moreover, it appears that speech and nonspeech are processed by different hemispheres of the brain throughout the life span.

Several general conclusions are suggested by the literature. First, speech processing in adults appears to differ in several ways from nonspeech processing. Specifically, evidence indicates that speech is perceived phonemically. Second, there is limited evidence that infants also perceive speech phonemically. Third, the auditory vs. linguistic processing hypothesis has not been adequately tested with infants because problematic response

measures have been used and discriminative stimuli have been selected in such a way that the auditory vs. linguistic cues cannot be isolated from one another.

Purpose of the Present Investigation

Whether or not infants perceive speech phonemically can be tested under conditions where two identical phones are signalled by two very different acoustic cues.

The purpose of the present investigation was to determine whether infants can categorize as the same two diverse acoustic cues which signal the same phone. If infants perceive the sounds phonemically, they should respond to the two tokens as if they were the same linguistic event. However, if infants process the sounds auditorily, they should perceive the sounds as different and be unable to make a similarity response.

Using differential head turning as the response measure, consider the following example: the infant is responding consistently with a right head turn to [di] and a left head turn to [ga]. A new stimulus [du] is presented. If the infant is perceiving the acoustic cues phonemically, a right head turn should occur, on the basis of the initial stop consonant. However, if he is perceiving the acoustic cues auditorily, head turning should be random because the cues are perceived as different.

METHOD

Subjects

The subjects were twelve home-reared infants residing in Ingham County, Michigan. There were eight male and four female infants ranging in age from 12 to 22 weeks (mean age = 17.6 weeks). The infants were obtained from answers to a written request distributed by pediatricians to their patients (see Appendix A). Permission for participation in the experiment was obtained in writing from each parent (see Appendix B).

Each infant's level of arousal was operationally defined as "quiet awake" as demonstrated by open eyes, occasional movements of the torso and extremities, and occasional vocalizations (Brackbill and Fitzgerald, 1969).

Two subjects were eliminated from the analysis because they failed to reach the criterion of four consecutive correct responses to the conditioning stimuli. Ten subjects remained in the analysis, three in each experimental group and four in the control condition. The measure of performance in this experiment was the frequency of correct right or left head turns to stimuli across the conditioning and test trials.

The stimuli were three synthetic monosyllabic sequences, /di/, /du/, and /ga/. The acoustic cues (i.e., F2 transitions) signalling perception of /d/ in synthetic /di/ and /du/ are highly divergent. That is, the F2 transition in /di/ shows a sharp rise in the frequency spectrum, whereas the F2 transition in /du/ shows a sharp fall. This difference in the F2 transition characteristics is the result of coarticulation from the consonant to the two different vowel environments. In the present experiment, the stimuli /di/ and /du/ were constructed so that the only available cue signalling perception of /d/ in the two vowel environments was the F2 transition. Even in natural speech the F2 transition plays a major role in perception of /d/. In fact, there are no known invariant acoustic cues which could signal perception of /d/ in these two contexts (Ronald Cole, personal communication, 1975).

Adults judge the vowels /i/, /u/, and /a/ to be equally dissimilar from one another (Pols, vanderKamp, & Plomp, 1969). Although this equivalence was established for adults, the selection of these three vowels reduces the possibility of infants' making a generalization response on the basis of vowel similarity.

All stimuli were synthetically produced on a PDP/9 computer using a terminal analog speech synthesis procedure (for a description of this procedure, see Klatt, 1974). Stimuli were synthesized without initial consonant

bursts. The fundamental frequency for all three sequences began at 103 Hz at 0 msec, rising to 125 Hz at 35 msec. At 85 msec, the fundamental frequency began dropping from 125 Hz, reaching 94 Hz at 215 msec and terminating at 50 Hz at 255 msec. (A schematized representation of the fundamental frequency contour is presented in Appendix C.)

The acoustic parameters of each CV sequence were as follows:

/ga/

F1: 200 Hz at 0 msec to 720 Hz at 45 msec
 F2: 1640 Hz at 0 msec to 1240 Hz at 40 msec
 F3: 2100 Hz at 0 msec to 2500 Hz at 45 msec
 F4: 3600 Hz constant
 F5: 4500 Hz constant

Formants are fixed for /a/:

F1: 720 Hz
 F2: 1240 Hz
 F3: 2500 Hz

/di/

F1: 180 Hz at 0 msec to 330 Hz at 15 msec
 F2: 2000 Hz at 0 msec to 2200 Hz at 40 msec
 F3: 2800 Hz at 0 msec to 3000 Hz at 40 msec
 F4: 3900 Hz at 0 msec to 3600 Hz at 40 msec

Formants are fixed for /i/:

F1: 269 Hz
 F2: 2200 Hz
 F3: 3000 Hz

/du/

F1: 180 Hz at 0 msec to 370 Hz at 15 msec
 F2: 1600 Hz at 0 msec to 1100 Hz at 15 msec
 F3: 2700 Hz at 0 msec to 2350 Hz at 15 msec
 F4: 3200 Hz constant
 F5: 4500 Hz constant

Formants are fixed for /u/:

F1: 330 Hz
 F2: 1100 Hz
 F3: 2300 Hz

(Schematized representations of stimuli characteristics can be seen in Appendix C. For spectrograms of each stimulus, see Appendix D.)

Apparatus

A schematic representation of the apparatus (Figure 1) and a description of the recorded data (Figure 2) can be seen on the following pages.

An Ampex 602-2 tape recorder (frequency response 50-15000 Hz, + 2 dB) was used for stimulus presentation. Channels 1, 3, and 4 of the tape recorder were routed through an audio channel selector (or manual switching device) such that each channel of the tape recorder could be manually selected.

The Audio Channel Selector received audio input from each channel of the tape recorder. The audio signal was then sent to an Ampex speaker (Model AA620) located in a

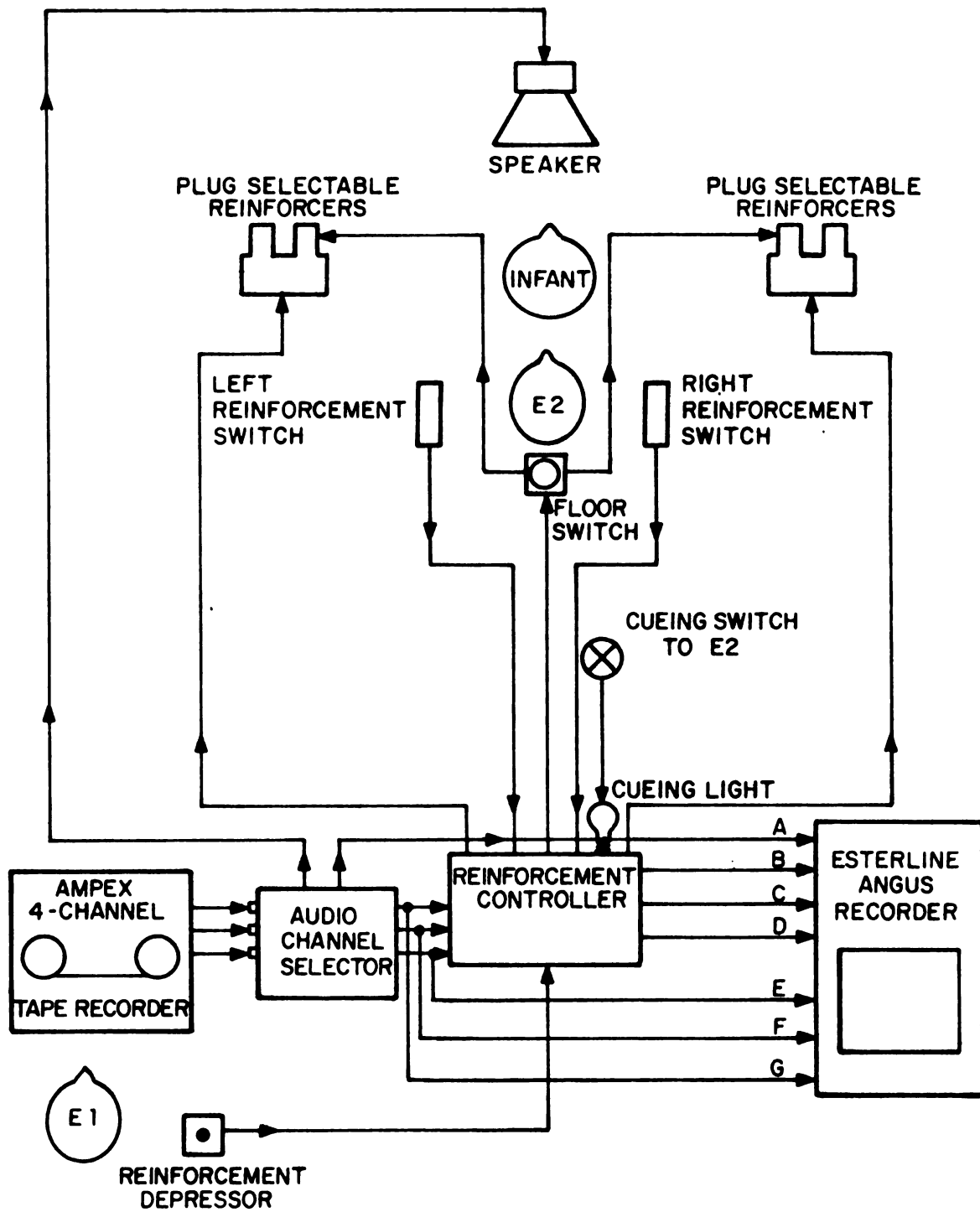


Figure 1. Apparatus Diagram

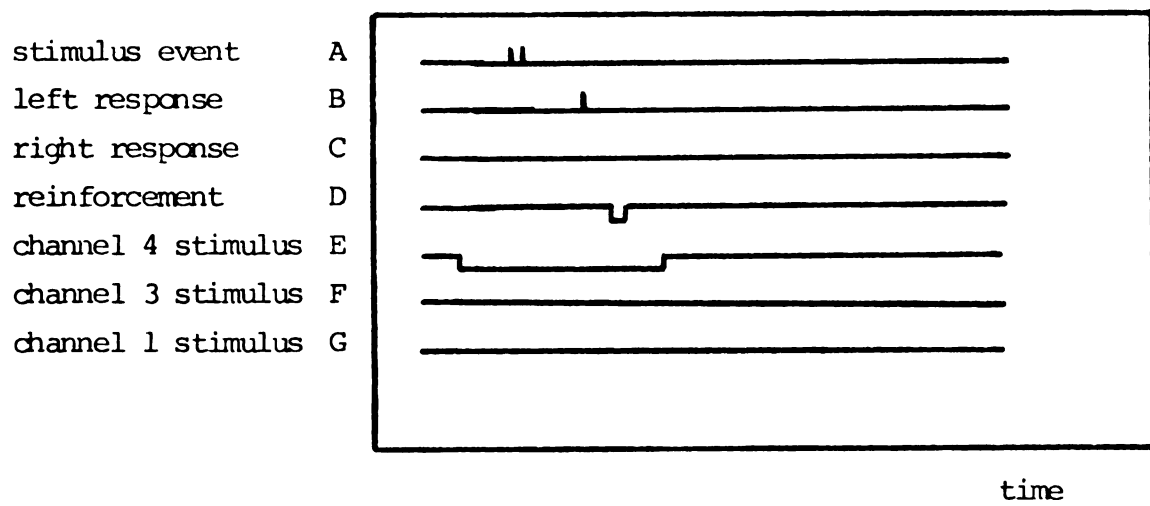


Figure 2. Sample of Recorded Data

sound attenuated booth one meter directly in front of the infant. Audio output from the Audio Channel Selector was also fed to an Esterline Angus Operation Recorder (Model A602X) where the occurrence of each stimulus event was recorded.

Each channel of the Audio Channel Selector was connected to a separate channel on the event recorder. The onset and offset of each channel was recorded on the event recorder. The onset and offset of each channel was also sent from the Audio Channel Selector to the Reinforcement Controller.

The Reinforcement Controller received input from both the Audio Channel Selector and the right and left reinforcement switches. These switches were located in the sound attenuated booth and were activated when the infant made a right or left head turn. Right and left responses were routed through the Reinforcement Controller to separate channels of the event recorder where they were recorded. The right or left response signal also was relayed through the Reinforcement Controller to the reinforcers. A correct response resulted in the activation of each reinforcer.

Output from the Reinforcement Controller also was fed through a small floor switch located inside the sound attenuated booth. Depression of this switch activated one red and one green blinking light (1 cm. in diameter) which were embedded in the ears of one of the right and

left reinforcers. Depression of the switch following stimulus presentation caused the lights to blink in the direction of a correct response.

The Esterline Angus Operation Recorder provided a record of the following: 1) the occurrence of reinforcement, 2) a left response, 3) a right response, 4) the stimulus event, 5) the onset and offset of [di] from Audio Channel 1, 6) the onset and offset of [du] from Audio Channel 3, and 7) the onset and offset of [ga] from Audio Channel 4.

Depression of a small switch in the sound attenuated booth activated a small cueing light located on top of the Reinforcement Controller outside the booth. This light signalled Experimenter 1 to switch channels. Extinction of the light signalled Experimenter 1 to present the stimulus.

A switch located on the floor outside of the booth to the right of Experimenter 1 was connected to the Reinforcement Controller. Depression of the switch stopped the presentation of reinforcement following a correct response. This switch was manually controlled by Experimenter 1 during the baseline phase of the experiment.

Design and Procedure

Infants were randomly assigned to one of three conditions: experimental condition di/ga, experimental condition du/ga, and control condition di/du (see Figure 3).

Fixed Parameters Across Conditions

Number of subjects: 4
 Presentation: randomized order
 Number of trials:

Phase 1: 10 presentations of each stimulus type define the baseline period on any given day

Phase 2: variable

Phase 3: the infant's behavior (i.e., a change of state) defines the length of the testing period on any given day four successive days of testing constitute the testing phase

Session X	Condition #	Exp. 1	Exp. 2	Control 3
PHASE 1 Baseline	stimuli	di/ga/du	du/ga/di	di/du/ga
	reinforcement	no	no	no
PHASE 2 Conditioning	discriminative stimuli	di/ga	du/ga	di/du
	reinforcement			
	1. continuous to criterion (four consecutive correct responses to the discriminative stimuli). 2. following attainment of the response criterion, either a) begin testing or b) terminate the session and begin testing on the following day. The length of the conditioning period preceding the establishment of the response criterion on any given day determines which of the two procedures is followed.			
PHASE 3 Testing	discriminative stimuli	di/ga	du/ga	di/du
	generalization stimulus	du	di	ga
	reinforcement			
	continuous discriminative stimuli: reinforced generalization stimulus: not reinforced			

Figure 3. Experimental Design

Each infant was conditioned to respond differentially to the two discriminative stimuli with either a right or left head turn. In each condition, the stimulus-response contingency was counterbalanced so that half of the subjects responded, for example, with a left head turn for /di/ and a right head turn for /ga/ and half of the subjects responded with a right head turn for /di/ and a left head turn for /ga/.

Each infant was tested individually approximately 1/2 hour after the last feeding. Infants were tested at the same time on each subsequent day of testing. Occasionally, an infant was tested twice in one day--one session in the morning and one session in the afternoon with testing times kept constant across days.

The experimental sessions took place in a small, semi-darkened sound attenuated booth. The infant was either seated on the floor (supported by Experimenter 2 who sat directly behind the infant) or in an infant seat at a 45° angle. The infant sat facing a speaker at a distance of one meter. Sounds were presented at a level of 75 dB (re: .0002 dynes /cm²). The parent was permitted to observe the session from inside the booth; however, he/she remained behind the infant out of the infant's visual field. Experimenter 2 also remained directly behind the infant and was responsible for reinforcing the infant's head turning responses.

The experiment consisted of three phases: baseline, conditioning, and testing. The number of phases completed during any one experimental session depended upon whether or not there was a change in the infant's level of arousal.

A single trial consisted of two repetitions of a single stimulus. During baseline, 20 tokens of each stimulus type were presented in random order for a total of 30 trials (or 60 tokens). A response was defined as a lateral right or left head turn from midline of 45° or greater that occurred within four seconds following a stimulus presentation. A subjective judgment was made by Experimenter 2 for determining whether or not a head turn occurred. A lateral head turn was counted as a response if the left or right reinforcer was in the infant's potential visual field. The reinforcers were placed so that the infant had to make a lateral head turn of at least 45° before he could see the reinforcer.

The conditioning phase began on a subsequent day. Conditioning began with the presentation of n trials of one discriminative stimulus. The number of trials presented was determined by each infant's anticipatory head turning response. When the infant spontaneously made two consecutive correct head turns in the same direction immediately following a stimulus presentation, the second discriminative stimulus was presented and the same procedure was followed. When the infant reached the response criterion of two consecutive correct anticipatory head

turns following stimulus presentation, the presentation sequence was changed to four consecutive trials of each stimulus type. This sequence presentation was maintained until the infant demonstrated a discriminative response. A discriminative response was defined as a correct head turn to one stimulus followed by a correct head turn to the second stimulus. For example, four trials of /di/ (correct response = right head turn) are presented. On the fourth trial the infant responds correctly with a right head turn. On the fifth trial /ga/ is presented and the infant responds correctly with a left head turn. This change in direction of response is operationally defined as a discriminative response. Following the demonstration of this response pattern, the order of presentation of each stimulus type was randomized under the constraint that no stimulus was presented more than four consecutive times.

If the infant did not make a spontaneous head turn in the correct direction following stimulus presentation, his head turning response was shaped through the presentation of one red and one green blinking cueing light, each embedded in the ears of two of the reinforcers (the dancing bears). The cueing lights were located approximately 75° to the right and 75° to the left of the infant's midline.

Each correct head turn was followed immediately by 2 1/2 seconds of reinforcement presented at approximately

a 75° angle to the right or left of the infant. Through pilot work, the two most effective reinforcers were found to be 1) a stationary 30 cm high hollow yellow plastic lion which was illuminated by a light bulb located inside the lion or 2) a 20 cm high toy dancing bear which rotated as it played the drums. Pilot work indicated that the reinforcer alone or alternating between these reinforcers maintained head turning at a high level throughout the session. Reinforcers were presented to each infant either 1) alone, 2) alternating within a session, 3) alternating from session to session, or 4) together in combination.

Experimenter 2 returned the infant's head back to midline immediately before the next stimulus was presented.

Four consecutive correct responses to the discriminative stimuli marked the end of the conditioning phase. The test phase generally began without interruption. However, this procedure was altered under the following condition: if the infant reached criterion towards the end of what marked an average conditioning session for that child (somewhere between 30 and 60 trials, depending upon the individual infant), the session was terminated and testing began on the following day. This procedure was followed in order to avoid testing the infant when he was approaching fatigue or satiation.

During Phase 3, a continuous reinforcement schedule was maintained and a novel (generalization) stimulus was

introduced. Responses to the discriminative stimuli were reinforced, the generalization stimulus was never reinforced. The generalization stimulus and the two discriminative stimuli were presented randomly. The length of each testing session was determined by the infant's level of arousal (Brackbill & Fitzgerald, 1969). Four successive days of testing marked the end of the testing phase.

RESULTS

Two infants were successfully conditioned to respond with directional head turns, one infant from the experimental group (di/ga) and one infant from the control group (di/du). In the test phase, directional responses to the test stimulus were random for both subjects. The experimental subjects' random responses to the test stimulus /du/ failed to support the linguistic hypothesis. The control subjects' random responses to /ga/, however, were as expected for the control condition. A third infant from the experimental condition di/ga showed signs of conditioning to the two discriminative stimuli towards the end of the test phase.

A striking feature of these data was the marked variability found in individual response patterns across time. Since group analysis would seriously misrepresent the data, the data were analyzed individually with the strength of the analysis lying in the large number of observations obtained for each infant. Group analysis was limited to situations where individuals formed homogeneous groups.

The results were analyzed by first determining which infants performed above chance expectations during the test phase of the experiment. Responses to the test

stimuli were then analyzed for these infants. Unconditioned infants were included in a separate analysis of characteristic response patterns and trends in individual performance.

Conditioning

In order to test the linguistic hypothesis, each infant had to first meet the criterion of a discriminative response to the two discriminative stimuli. Discrimination was measured by determining whether each infant's correct responses to the discriminative stimuli deviated from that expected by chance. Each infant's response frequencies to the discriminative stimuli were compared with those frequencies expected by chance under the null hypothesis. The null hypothesis assumes that, given a spontaneous lateral head turn and no response bias, the probability of a right or left response is 0.5.

Results showed that two infants achieved the discrimination criterion: one from the experimental group di/ga and one from the control group, di/du. Neither infant showed a response bias (see Appendix E). Results for all infants are summarized in Table 1.

A visual representation of the general course and pattern of conditioning for the two conditioned infants is shown in Figures 4 and 5. Trials across conditioning and test phases were segmented into twenty-trial blocks. The proportion correct was derived from the frequency of

Table 1. Comparison of Correct and Incorrect Response Frequencies to Discriminative Stimuli Across Test Phase

Subject	Observed Frequency		Expected Frequency		Proportion Correct Across Test Phase
	Correct	Incorrect	Correct	Incorrect	
Experimental di/ga					
1	36	23	29.5	29.5	2.44
2	20	6	13	13	6.50*
3	36	27	31.5	31.5	1.01
Experimental du/ga					
4	45	37	41	41	0.59
5	15	14	14.5	14.5	0.00
6	40	26	33	33	2.60
Control di/du					
7	13	8	10.5	10.5	0.76
8	24	19	21.5	21.5	0.37
9	49	20	34.5	34.5	11.36*
10	32	23	27.5	27.5	1.16
					0.62
					0.56
					0.71
					0.58

* $\chi^2 > 3.84$; 1 df; $p \leq .05$

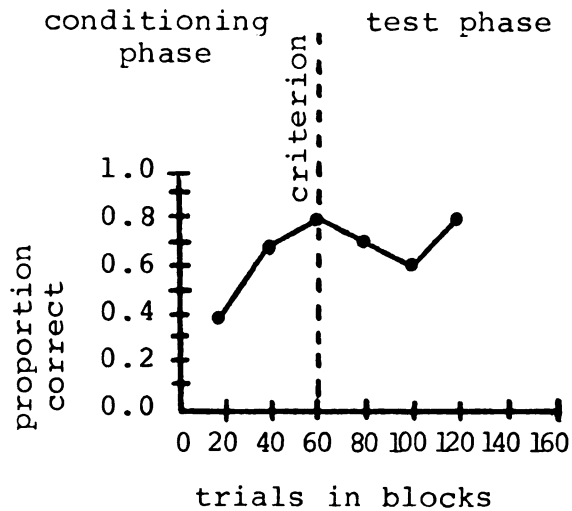


Figure 4. Conditioning Performance Across Conditioning and Test Phase for Subject 2, Experimental Condition di/ga.

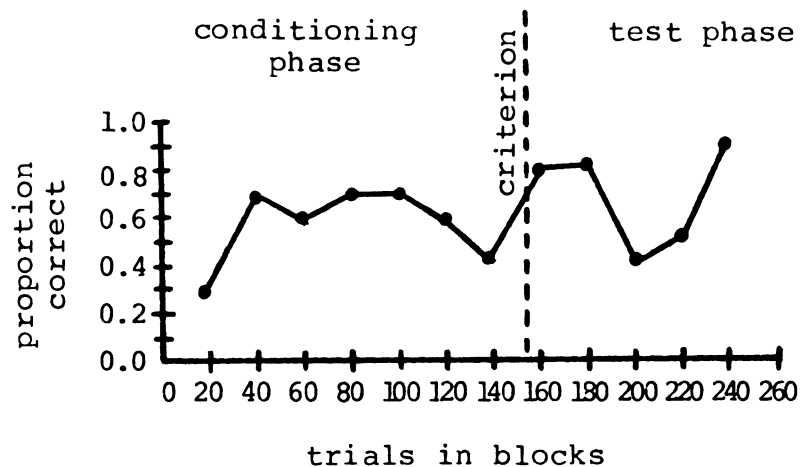


Figure 5. Conditioning Performance Across Conditioning and Test Phases for Subject 9, Control Condition di/du.

correct and incorrect responses. Incorrect responses included both responses in the wrong direction and no-responses. (Response frequencies and correct response proportions for the two conditioned infants are found in Appendix F.)

Examination of the conditioning curves for these two infants reveal no marked differences in the rate or general pattern of conditioning. Although the criterion level was reached sooner in the conditioning process for the experimental subject (Trial 60) as compared with the control subject (Trial 155), both infants were performing above chance expectations by Trial 40. The control subject's average performance following her initial increase remained above chance for the subsequent 80 trials, indicating that she, in fact, had achieved conditioned discrimination prior to attainment of the response criterion.

The conditioned infants' performance is characterized by a relatively stable response pattern as compared to the highly variable response pattern observed for the unconditioned infants (see Appendix G1-7). The overall course of conditioning for the conditioned infants also generally increased across conditioning trials, a trend not represented in the performance of most unconditioned infants.

A modification of the backward learning curve, described by Zeaman and House (1962), was used to compare the way in which the two conditioned infants approached a conditioned level of responding. This information is

displayed in Figure 6 in a backward conditioning curve. The backward curve was produced by shifting each infant's conditioning curve to the right. The starting point on the graph is the point at which each infant attained and prolonged a performance level above chance (or 0.7 correct). This criterion was selected instead of the a priori criterion level because it better represented the point at which the conditioned state was actually reached. This point was at Trial 40 for both the experimental and control subject (see Figures 4 and 5). Trial 40 therefore became Trial 0 on the new graph. The preceding block of twenty trials is indicated by a minus sign on the abscissa of the graph. Both infants' initial peak level of performance is therefore equated in space, providing a comparison of the response slope of each curve for the period immediately preceding attainment of above chance responding.

The response slopes in Figure 6 are very similar, indicating that both the rate and the approach to criterion were the same for both infants.

Test of the Linguistic Hypothesis

The linguistic hypothesis was tested by comparing each conditioned infant's response frequencies to the test stimuli against those frequencies expected under the null hypothesis. The null hypothesis assumes that given a spontaneous lateral head turn, the probability of a right or left turn equals 0.5.

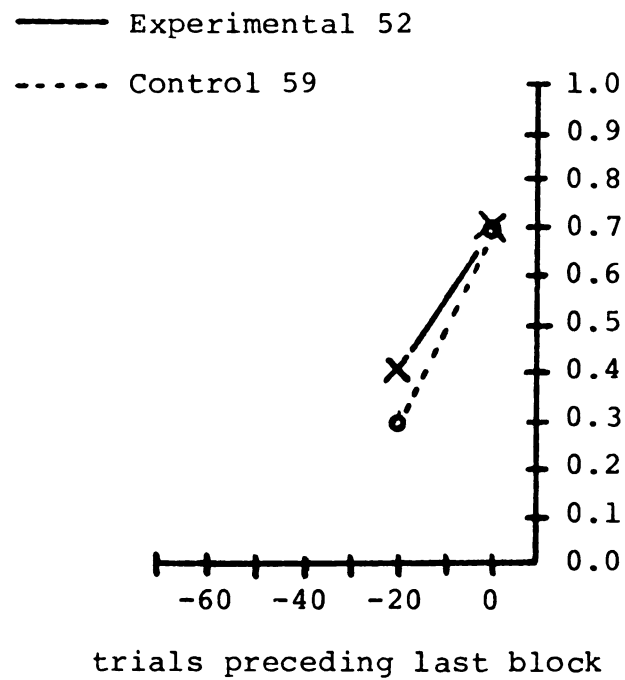


Figure 6. Backward Conditioning Curve Showing Approach to Criterion for Conditioned Subjects 2&9.

It was hypothesized that infants in the experimental group would generalize their response to the test stimulus in the direction of the discriminative stimulus which shared the same phoneme, /d/. It was hypothesized further that infants in the control group would not show a generalization response to the test stimulus /ga/, since it shared no acoustic or linguistic similarity with either of the discriminative stimuli.

Results for the two conditioned infants are shown in Table 2.

Table 2. Conditioned Infants' Correct Response Performance to Test Stimuli Across Test Phase

Subject	Observed Frequency			Expected Frequency			Proportion Correct Across Test Phase
	Cor- rect	Incor- rect	Row Total	Cor- rect	Incor- rect	χ^2	
Experi- mental di/ga							
2	9	14	23	11.5	11.5	0.69	0.39
Control di/du							
9	13	10	23	11.5	11.5	0.17	0.56

* $\chi^2 \geq 3.84$; df = 1; $p \leq .05$

The experimental subject's directional responses to the test stimulus /du/ were random, lending no support to the linguistic hypothesis. The control subject's directional responses to the test stimulus /ga/ were also random, as

expected for the control condition. A summary of the results for the two conditioned infants are shown in Table 3.

Analysis of Unconditioned Infants

Recall that infants were defined as conditioned only if they demonstrated performance discrimination above chance expectations for the two discriminative stimuli. Two infants in this experiment met that criterion; eight infants did not. Further analysis of the unconditioned infants, however, revealed the following: 1) the number of head-turning responses to discriminative stimuli increased across experimental trials for all infants, 2) all infants responded with more correct than incorrect head turns to the discriminative stimuli, and 3) one of the infants showed signs of conditioning across the test phase of the experiment.

Conditioned Head-Turning

The eight unconditioned infants were grouped in an analysis of increases in the frequency of head-turning responses to discriminative stimuli across baseline and conditioning trials. (The infants' response frequencies are tabled in Appendix H. A summary of the results are shown in Figure 7. Conditioned infants' responses are tabled but not graphed.)

Average responses were plotted in ten-trial blocks across baseline and in twenty-trial blocks across the conditioning and test phases. Two infants contributed less than 60 trials across the conditioning phase, leaving the

Table 3. Summary of Results for Conditioned Subjects 2 and 9

Subject	Age in Months	Condition	Test Stimulus	Responses Over Testing Phase									
				Baseline Responses		Discriminative Stimuli						Test Stimuli	
				Left	Right	Cor- rect	Incor- rect	Proportion Correct	χ^2	Cor- rect	Incor- rect	Proportion Correct	χ^2
Experi- mental													
2	5	di/ga	du	10	9	20	6	0.77	*6.5	9	14	0.39	0.69
Control													
9	4	di/du	ga	13	10	49	20	0.71	*11.36	13	10	0.56	0.17

* $\chi^2 > 3.84$; $df = 1$; $p \leq .05$

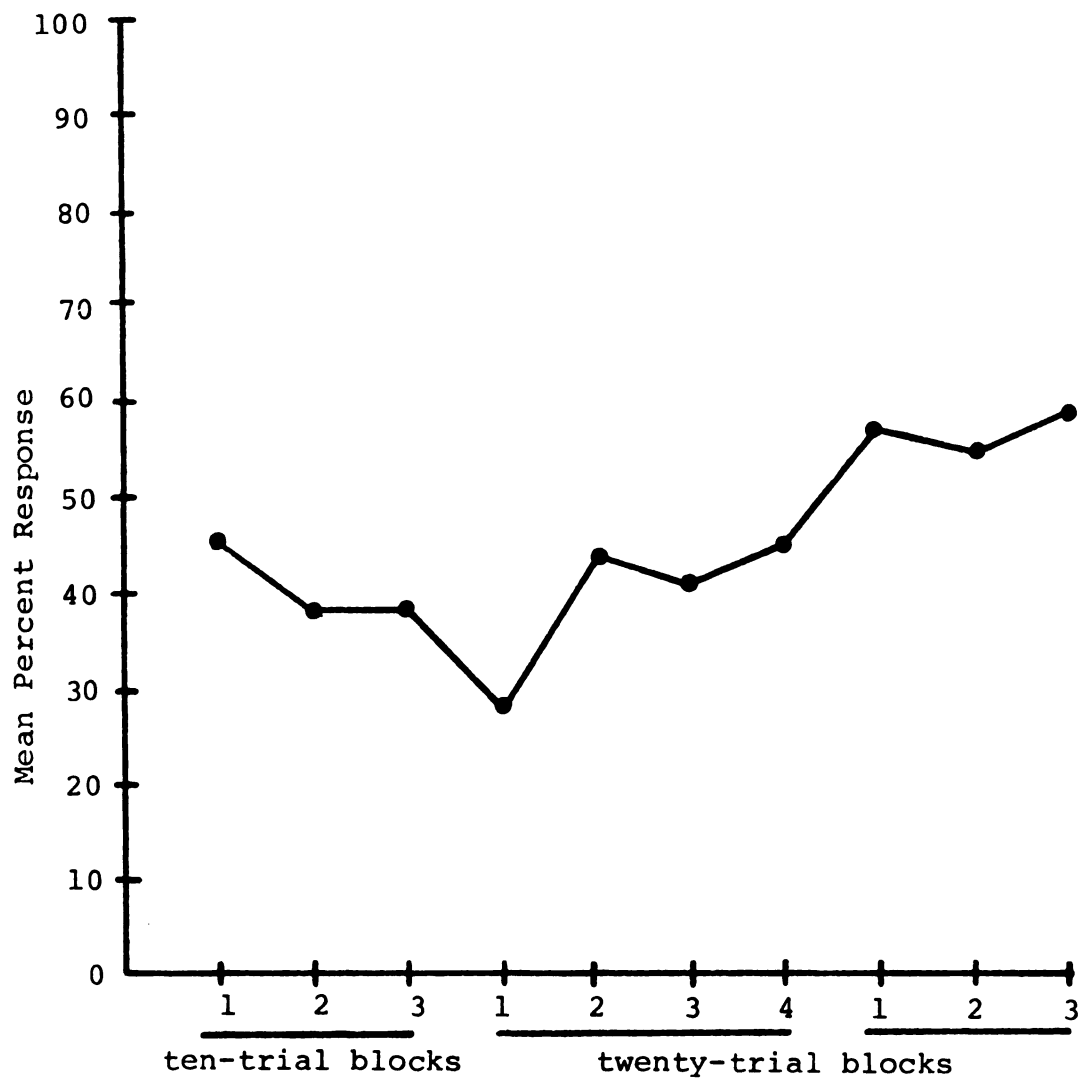


Figure 7. Mean Percent Response to Conditioning for Unconditioned Infants.

third and fourth trial blocks with an n of seven and six, respectively.

The response pattern in Figure 7 is characterized by a strong increase in mean level of responding across trials. The curve itself is ogival in shape, showing its greatest acceleration across the conditioning phase of the experiment. This curve demonstrates that although infants were not conditioned in directional head-turning, conditioning did influence their level of head-turning activity.

(Individual conditioning curves for the unconditioned infants are included in Appendix G1-7.)

Directional Responses

Although the unconditioned directional responses to the discriminative stimuli did not differ from chance, all infants responded with more correct than incorrect head turns (see Table 1, page 49). Further, the infant with the greatest discrepancy in correct and incorrect responses (Subject 1) showed a sharp rise in conditioning performance across the test phase (see Figure 8, next page). This configuration suggests that Subject 1 was in the process of being conditioned and may have reached the conditioned state with continued experimentation.

(A summary of response frequencies to discriminative stimuli for all infants across conditioning and test phases is presented in Appendix I.)

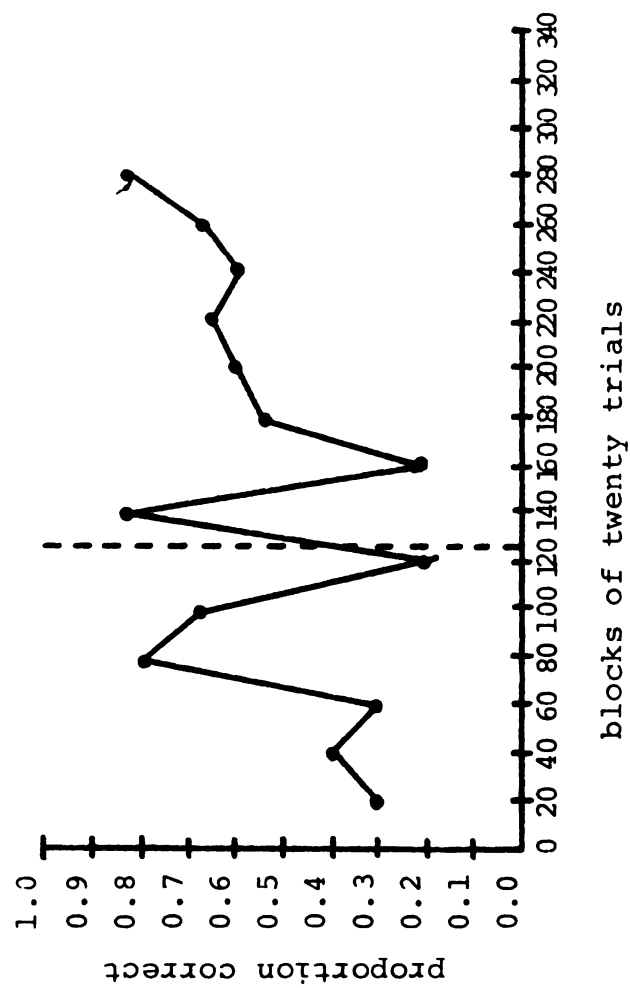


Figure 8. Conditioning Performance Across Conditioning and Test Phase for Subject 1, Experimental Condition di/ga.

DISCUSSION

The purpose of the present study was to determine whether infants code speech linguistically or auditorily. Specifically, it was predicted that infants would respond to the linguistic characteristics of speech sounds by grouping together two consonant-vowel monosyllables which shared the same consonant but whose consonants were signalled by very different acoustic cues.

In order to test the hypothesis, infants were first required to discriminate stimuli with directional head turns. Two infants succeeded at this task: one infant from an experimental group successfully discriminated between /di/ and /ga/ and one infant from the control group successfully discriminated between /di/ and /du/. Generalization responses to the test stimulus were subsequently measured. The control subject's responses to the test stimulus /ga/ were random, as expected for the control condition. The experimental subject's responses to /du/ were also random, failing to support the linguistic hypothesis.

The experimental subject's failure to support the linguistic hypothesis may have been due to the overriding influence of the vowel in making a categorization response. In all three CV stimuli, the vowel is perceptually more

salient than the consonant. The steady-state vowels /i/, /u/, and /a/ are more intense and longer in duration, characterized by higher energy concentrations in formants extending over 200 msec (see Appendix C). In contrast, the formant transitions which define the stop consonants /d/ and /g/ are weaker in energy and extend over a much shorter period (less than 35 msec). For adults, the vowels /i/, /u/, and /a/ are perceptually equidistant. Assuming that these vowels are also perceptually equidistant for infants (a result shown by Fodor et al., 1975), generalization responses to test stimuli on the basis of the vowel would serve as an explanation for the random responses obtained for both the experimental and control subjects. Since only two subjects were tested, however, these suggestions are only speculative.

Nine of the ten infants did not demonstrate a response bias across the baseline phase. One five-month-old infant (Subject 3) showed a strong response bias to the right. The bilateral responses found for infants in the age range three- to five-and one-half months were in contrast to other studies showing a bias to the right for four-month-olds (Siqueland, 1964) and a bias to the left for three-month-olds (Levison & Levison, 1967).

Neonates characteristically show a response bias to the right which diminishes as the infant becomes neurologically more mature (Brockbill, 1970). Although the equivocal results concerning the direction of the response bias

in young infants are difficult to explain, the lack of a response bias in this study may be accounted for by the older age of the infants. Six infants in this study were approximately five-months-old, three infants were approximately four-months-old, and only one infant was three-months-old (see Appendix I).

Fluctuations in state both within and across experimental sessions may partially account for the marked within-subject variability found in the responses of the unconditioned infants. Although each session was terminated when the infant exhibited noticeable state fluctuations (e.g., crying or fussing), changes in attention or motivation could not be assessed. For example, during experimental sessions, Subjects 3, 6, and 8 (Appendix G1, G4, and G6) achieved a high level of correct responding which then ceased abruptly and never recovered. This suggests a transient conditioning effect. Why the conditioned response could not be recovered is unknown; however, state fluctuations and reinforcement satiation are possible explanations.

Limitations of This Research

Procedural problems were encountered during measurement of the head-turning response. When the infant's head was positioned at midline, Experimenter 2 signalled Experimenter 1 to present the stimulus. The latency between the signal to Experimenter 1 and the actual occurrence of the

stimulus was approximately two seconds. Because the infant was often making bilateral responses during this period, Experimenter 2 was unable to maintain the infant's head at midline. This resulted in responses which did not originate from midline and could not therefore be assessed as either correct or incorrect.

Since no mechanical head-turning apparatus was used, measurement of a criterion head-turn was based upon the subjective judgment of Experimenter 2. A lateral response had to exceed 45° in order to be counted as a head-turn; however, since Experimenter 2 had to estimate whether or not the 45° criterion was reached, a response of $60^{\circ} \pm 15^{\circ}$ was operationalized. The use of a range of responses rather than a response locus may have made it more difficult for some infants to learn the discrimination. Further difficulty may have been introduced by erroneously reinforcing a correct response which did not originate from the midline position.

Since there was no adequate a priori method for identifying the point at which the infant reached a conditioned state and could be subsequently tested, a non-stringent criterion of four consecutive correct responses was employed. However, post hoc analyses revealed that one infant (Subject 9) was conditioned before she reached criterion (or before she received any test trials). To avoid this situation, test trials could be introduced following a given number of conditioning trials regardless

of the infant's performance up to that point. A post hoc analysis would then be used to identify the conditioned period and test trials prior to that period would be disregarded. Such a procedure would prevent the loss of test-trial data during a time when the infant was conditioned.

Implications for Future Research

If the vowel, rather than the consonant, serves as the basis for making a generalization response, the generalization paradigm is unsuitable for testing whether infants respond to the linguistic characteristics of the stop consonant, /d/. However, a discrimination paradigm may be employed using two tokens of the same phonemic sequence, /du/. The two tokens (/du/ and /du/) can be synthesized so that the linguistic cues /d/ and /d/ are perceptually identical but the acoustic cues signalling perception of each /d/ are highly divergent (Ronald Cole, personal communication, 1975). Although the discrimination paradigms (i.e., high-amplitude sucking and heart rate) are problematic, these methods avoid the serious problem of vowel dominance and allow discrimination measures to be obtained from a larger number of infants.

Because of the difficulty in teaching infants to make a discriminative response using the head-turning paradigm, this particular paradigm does not appear to be a fruitful means for studying speech sound discrimination or categorization. In a recent unpublished report, Morse,

Leavitt, Donovan, Kolton, Miller, and Judd-Engel (1975) tested thirty-nine infants and encountered similar problems using the same paradigm. Only three infants acquired the discriminative response and infants satiated without novel reinforcement.

SUMMARY AND CONCLUSIONS

This research attempted to determine whether or not infants could categorize two CV syllables which shared the same initial stop consonant, /d/, but which were signalled by highly divergent acoustic cues. Two of twelve infants met the conditioning criterion of the experiment and their categorization responses were subsequently measured. Neither infant demonstrated a categorization response. The random responses to /du/ by the infant in the experimental group, di/ga, failed to support the linguistic hypothesis. The random responses to /ga/ by the infant in the control condition, di/du, were as predicted for the control condition.

The hypothesis examined in this study may not have been adequately tested because of two problems. First, the salience of the vowel in the CV sequences selected may be determinant in making categorization responses. Second, many infants did not acquire the initial discriminative responses required to test the linguistic hypothesis. It is concluded that the hypothesis may be best examined by testing for discrimination of two different acoustic cues that signal perception of /d/ in the same linguistic sequences, /du/ and /du/, using a high-amplitude sucking or a heart-rate habituation paradigm.

BIBLIOGRAPHY

- Brackbill, Y. & Fitzgerald, H. E. Development of the sensory analyzers during infancy. Advances in Child Development and Behavior, 1969, 4, 173-208.
- Butterfield, E. C. & Cairns, G. F. Discussion summary-- infant reception research. In R. L. Schiefelbusch and L. L. Lloyd (Eds.), Language Perspectives-- Acquisition, Retardation, and Intervention. Baltimore: University Park Press, 1974.
- Cohen, R. Differential cerebral processing of noise and verbal stimuli. Science, 1971, 172, 599-601.
- Cole, R. & Scott, B. Toward a theory of speech perception. Psychological Review, 1974, 81, 348-374.
- Cutting, J. E. Different speech-processing mechanisms can be reflected in the results of discrimination and dichotic listening tasks. Haskins Laboratories: Status Report on Speech Research SR-37/38, 1974, 39-53.
- Cutting, J. E. & Eimas, P. D. Phonetic feature analyzers and the processing of speech in infants. Haskins Laboratories: Status Report on Speech Research SR-37/38, 1974, 45-63.
- Cutting, J. E. & Rosner, B.S. Categories and boundaries in speech and music. Perception and Psychophysics, 1974, 16, 564-571.
- Day, R. S., Cutting, J. E., & Copeland, P. M. Perception of linguistic and nonlinguistic dimensions of dichotic stimuli. Haskins Laboratories: Status Report on Speech Research SR-31/32, 1971, 193-197.
- Day, R. S. & Wood, C. C. Interactions between linguistic and nonlinguistic processing. Haskins Laboratories: Status Report on Speech Research SR-31/32, 1971, 185-192.

- Eimas, P. D. Speech perception in early infancy. In L. B. Cohen and P. Salapatek (Eds.), Infant Perception: From Sensation to Cognition. Volume II: Perception of Space, Speech, and Sound. New York: Academic Press, 1975.
- Eimas, P. D., Siqueland, E. R., Jusczyk, P. & Vigorito, J. Speech perception in infants. Science, 1971, 171, 303-306.
- Fodor, J. A., Garrett, M. F., & Brill, S. L. Pi ka pu: the perception of speech sounds by prelinguistic infants. Perception and Psychophysics, 1975, 18, 74-78.
- Hawles, T. Effects of dichotic fusion on the perception of speech. Unpublished doctoral dissertation, University of Minnesota, 1969.
- Kimura, D. Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology, 1961, 15, 166-171.
- Kimura, D. Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology, 1964, 16, 355-358.
- Kimura, D. Functional asymmetry of the brain in dichotic listening. Cortex, 1967, 3, 163-178.
- Kuhl, P. K. & Miller, J. D. Speech perception by the chinchilla: voiced-voiceless distinction in alveolar plosive consonants. Science, 1975, 190, 69-72.
- Liberman, A. M. The grammars of speech and language. Cognitive Psychology, 1970, 1, 301-323.
- Liberman, A. M., Delattre, P. C., & Cooper, F. S. Some cues for the distinction between voiced and voiceless stops in initial position. Language and Speech, 1958, 1, 153-167.
- Liberman, A. M., Harris, K. S., Kinney, J. A., & Lane, H. The discrimination of relative onset-time of the components of certain speech and non-speech patterns. Journal of Experimental Psychology, 1961, 61, 379-388.
- Liberman, A. M., Cooper, F. S., Shankweiler, D. P., & Studdert-Kennedy, M. Perception of the speech code. Psychological Review, 1967, 74, 431-461.

BIBLIOGRAPHY

- Matsumiya, Y., Tagiliasco, V., Lombroso, C. T., & Goodglass, H. Auditory evoked response: meaningfulness of stimuli and interhemispheric asymmetry. Science, 1972, 175, 790-792.
- Mattingly, I. G. & Liberman, A. M. The speech code and physiology of language. In K. N. Leibovic (Ed.), Information Processing in the Nervous System. New York: Springer-Verlag, 1969, pp. 97-117.
- Mattingly, I. G., Liberman, A. M., Syrdal, A. K., & Hawles, T. Discrimination in speech and nonspeech modes. Cognitive Psychology, 1971, 2, 131-157.
- Moffitt, A. R. Consonant cue perception by twenty-to twenty-four-week-old infants. Child Development, 1971, 42, 717-731.
- Molfese, D. L., Freeman, R. B., & Palmero, D. S. The ontogeny of brain lateralization for speech, and nonspeech stimuli. Brain and Language, 1975, 2, 356-368.
- Morrell, L. K. & Salamy, J. G. Hemispheric asymmetry of electrocortical responses to speech stimuli. Science, 1971, 174, 164-166.
- Morse, P. A. The discrimination of speech and nonspeech stimuli in early infancy. Journal of Experimental Child Psychology, 1972, 14, 477-492.
- Morse, P. A., Leavitt, L. A., Donovan, W. L., Kolton, S., Miller, C. L. & Judd-Engel, N. Head-turning to speech: explorations beyond the heart and the pacifier. Infant Development Laboratory: Research Status Report #1, Harry A. Waisman Center, University of Wisconsin, 1975.
- Siqueland, E. R. & DeLucia, C. Visual reinforcement of nonnutritive sucking in human infants. Science, 1969, 165, 1144-1146.
- Stevens, K. N. & Halle, M. Remarks on analysis by synthesis and distinctive features. In W. Walther-Dunn (Ed.), Models for the Perception of Speech and Visual Form. Cambridge, Mass.: M.I.T. Press, 1967.
- Stevens, K. N. & Klatt, D. H. Role of formant transitions in the voiced-voiceless distinction for stops. Journal of the Acoustical Society of America, 1974, 55, 653-659.

- Studdert-Kennedy, M. & Shankweiler, D. Hemispheric specialization for speech perception. Journal of the Acoustical Society of America, 1970, 48, 579-594.
- Studdert-Kennedy, M., Shankweiler, D., & Pisoni, D. Auditory and phonetic processes in speech perception: evidence from a dichotic study. Cognitive Psychology, 1972, 3, 455-466.
- Trehub, S. Infants' sensitivity to vowel and tonal contrasts. Developmental Psychology, 1973, 9, 91-96.
- Trehub, S. & Rabinovitch, M. S. Auditory-linguistic sensitivity in early infancy. Developmental Psychology, 1972, 6, 74-77.
- Wood, C. C., Goff, W. R., & Day, R. S. Auditory evoked potentials during speech perception. Science, 1971, 173, 1248-1251.
- Wood, C. C. Parallel processing of auditory and phonetic information in speech perception. Haskins Laboratories: Status Report on Speech Research SR-35/36, 1973.

APPENDICES

APPENDIX A

LETTER TO PARENTS

APPENDIX A

LETTER TO PARENTS

RESEARCH IN INFANT SPEECH PERCEPTION

- PURPOSE:** An investigation of the speech perceptual capabilities of young infants is presently being conducted through the Department of Audiology and Speech Sciences at Michigan State University. The purpose of the project is to determine if preverbal infants respond to speech stimuli in the same manner as adults do.
- AGE OF INFANTS:** three to six months. The experiment will run until June 1 so if your child is three months by about May 15 he will qualify.
- BACKGROUND:** It was previously thought that infants from 0 to about 10 or 12 months of age heard speech as noise. There is recent evidence to suggest, however, that infants hear speech during this period in the same manner as adults do. This project is aimed at determining more precisely the way in which infants do perceive speech.
- TASK:** The task involves having the infant listen to speech sounds presented through a speaker. He is taught to turn his head either to the left or right when he hears one of the sounds. Each correct head turn is reinforced with an illuminated yellow plastic lion or a toy dancing bear.
- LENGTH OF EXPERIMENT:** Each session will last approximately 1/2 hour. The number of sessions required depends upon how quickly the infant learns the task. It may take between 10 and 15 sessions for learning to take place. Therefore, please do not sign up unless you are willing and able to make this kind of commitment.
- TRANSPORTATION:** Experimenters can provide transportation.
- PLACE:** Speech and Hearing Clinic, Michigan State University.
- WHOM TO CONTACT:** Kris King

PHONE NUMBER: If you are interested and can make the commitment necessary to complete the experiment, please call me at the Speech and Hearing Clinic, 353-5107.

BENEFIT: This is a difficult experiment to execute because of the time required for training. The results of the experiment, however, will greatly contribute to our understanding of the normal speech perception process and its development. It will also serve as the basis for our understanding of speech and language problems in early childhood.

All participants will receive a summary of the research findings.

Thank you for your consideration.

Sincerely,

Kris King
Doctoral Candidate
Department of Audiology and
Speech Sciences

APPENDIX B

PARENTAL CONSENT AND RELEASE FORM

APPENDIX B

PARENTAL CONSENT AND RELEASE FORM

I give consent for my child to participate in an investigation of infants' ability to perceive speech. I understand the purpose and procedure of the experiment as it has been explained to me. I understand that the individual data obtained from my child will be kept confidential and that names will not be used when reporting data from individual subjects. I further understand that I may discontinue my child from participation in the experiment at any time, and that I may have my child's data destroyed if I so desire. I understand that I will receive a summary of the results of this experiment when it is available.

Mailing Address:

Signature

Name (please print)

Date

Address

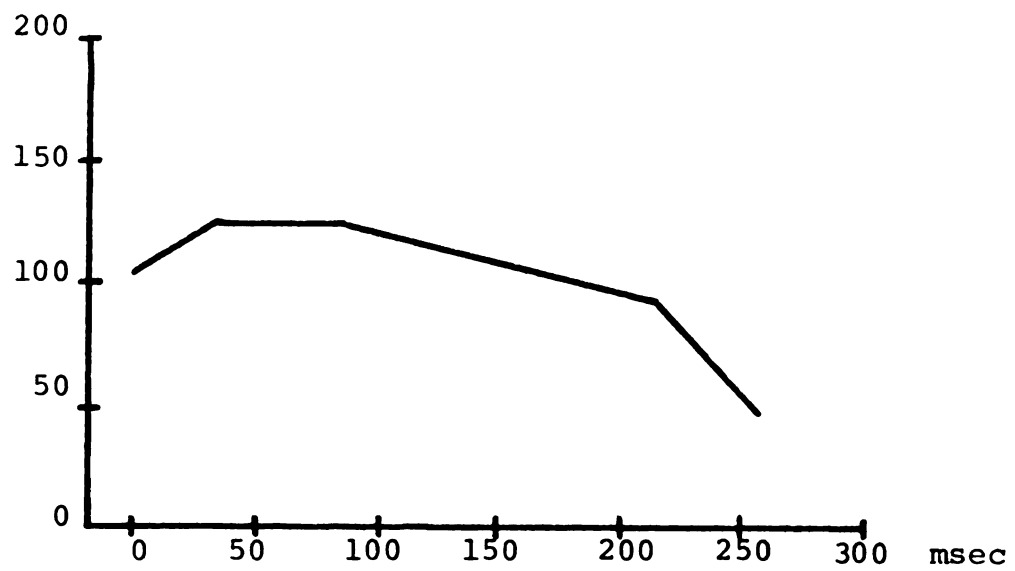
City

Zip

APPENDIX C

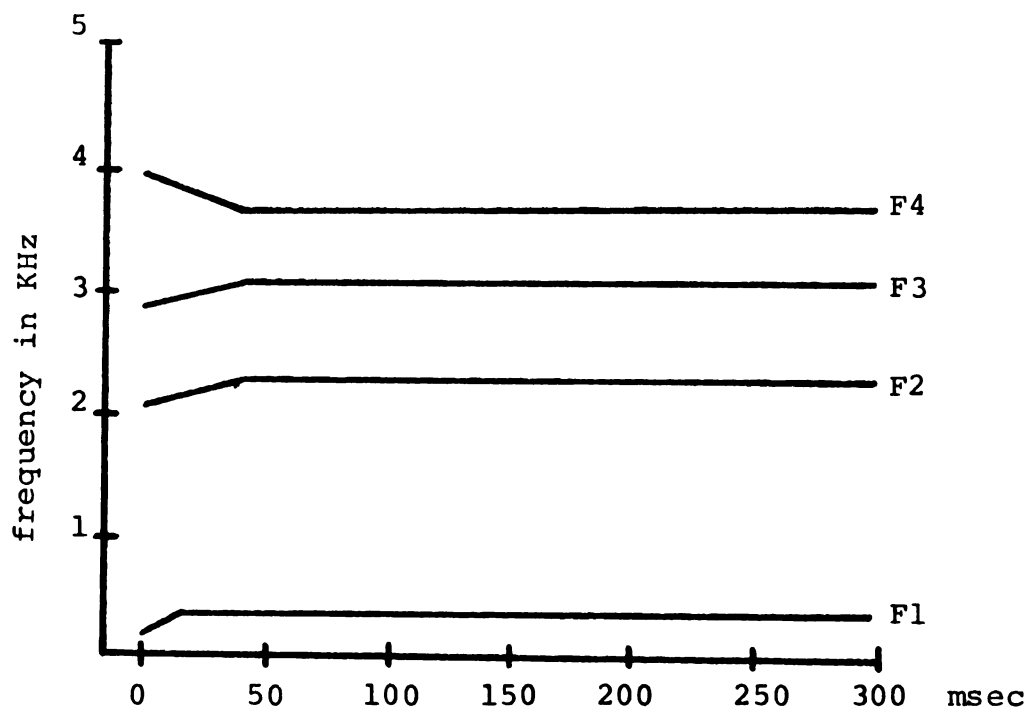
SCHEMATIC DESCRIPTION OF SPEECH STIMULI

APPENDIX C



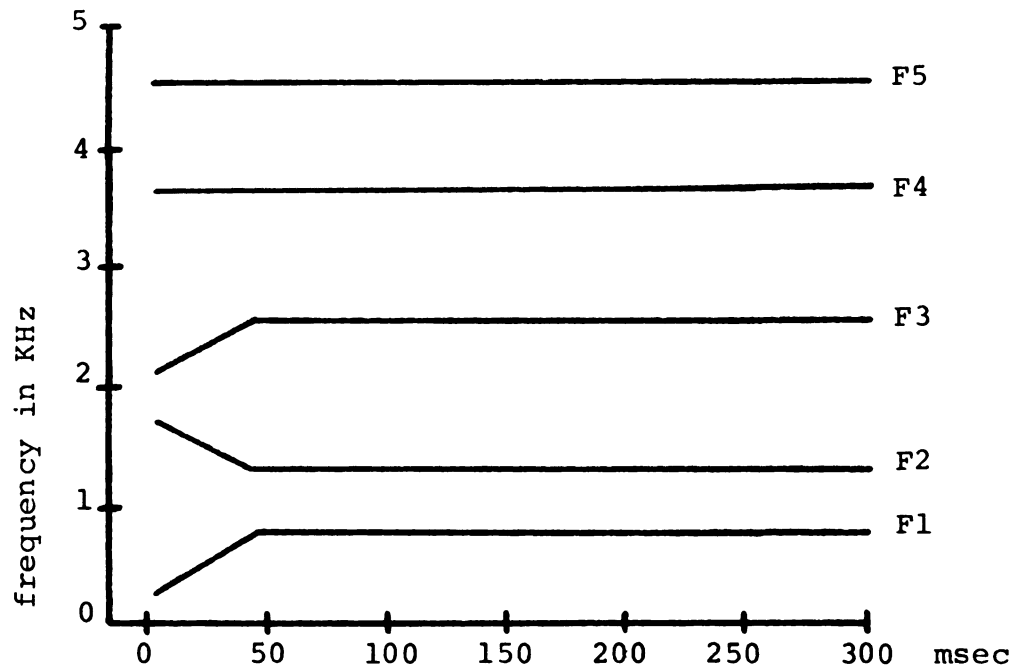
C1. Fundamental Frequency Contour for
Stimuli /di/, /du/, and /ga/.

APPENDIX C



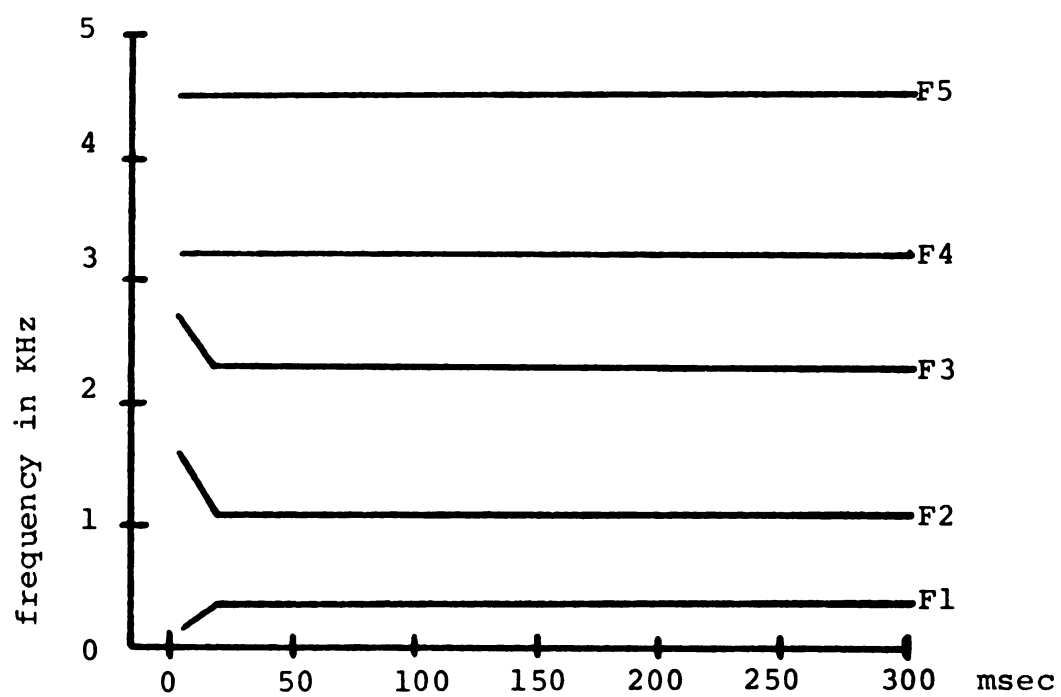
C2. Schematic Representation of Formant Structure for /di/.

APPENDIX C



C3. Schematic Representation of Formant Structuring for /ga/.

APPENDIX C



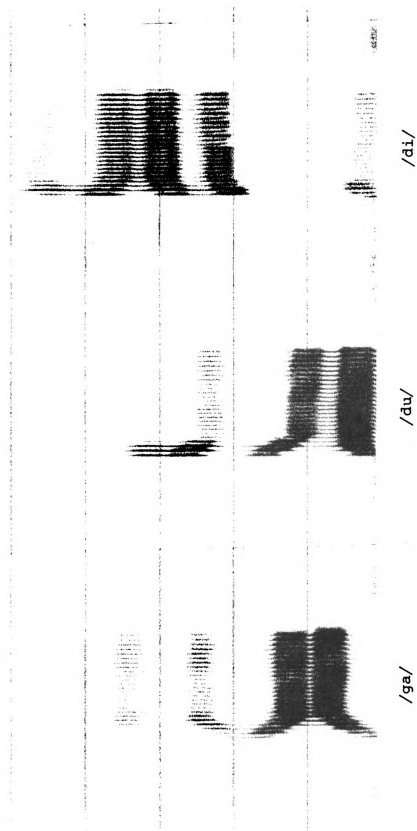
C4. Schematic Representation of Formant Structure for /du/.

APPENDIX D

SPECTROGRAMS

APPENDIX D

SPECTROGRAMS



APPENDIX E

FREQUENCIES OF LEFT AND RIGHT RESPONSES ACROSS BASELINE

APPENDIX E

Frequencies of Left and Right Responses Across Baseline

Condition	Sub- ject	Observed Frequency		Row Total	Expected Frequency		x ²
		Left	Right		Left	Right	
<u>Experimental</u>							
di/ga	1	5	8	13	6.5	6.5	.35
di/ga	2	10	9	19	9.5	9.5	.00
di/ga	3	2	17	19	9.5	9.5	*10.32
<u>Experimental</u>							
du/ga	4	12	10	22	11.0	11.0	.02
du/ga	5	4	2	6	3.0	3.0	no test
du/ga	6	11	12	23	11.5	11.5	.00
<u>Control</u>							
di/du	7	3	0	3	1.5	1.5	no test
di/du	8	2	2	4	2.0	2.0	no test
di/du	9	13	10	23	11.5	11.5	.20
di/du	10	5	4	9	4.5	4.5	no test

* $\chi^2 \geq 3.84$; $df = 1$; $p \leq .05$

no test: χ^2 statistic could not be computed for expected frequencies less than 5

APPENDIX F

CORRECT AND INCORRECT RESPONSE FREQUENCIES TO
DISCRIMINATIVE STIMULI ACROSS CONDITIONING AND
TEST PHASES FOR CONDITIONED SUBJECTS 2 AND 9

APPENDIX F

Correct and Incorrect Response Frequencies to Discriminative Stimuli Across Conditioning and Test Phases for Conditioned Subjects 2 and 9

Condition	Sub- ject	Response Category	Conditioning Trials in Blocks											
			20	40	60	80	100	120	140	160	180	200	220	240
Experimental	2	Correct	3	5	10	7	5	6						
		Incorrect	4	2	3	3	2	1						
		No- response	0	0	0	1	1	0						
		Proportion Correct	.43	.71	.77	.70	.60	.80						
Control	9	Correct	1	6	7	8	5	6	5	9	12	6	6	16
		Incorrect	0	1	0	2	2	0	6	3	1	5	6	2
		No- response	2	2	4	1	0	4	2	0	2	3	1	0
		Proportion Correct	.33	.67	.64	.73	.71	.60	.38	.75	.80	.43	.46	.89

APPENDIX G

CONDITIONING PERFORMANCE ACROSS CONDITIONING AND TEST PHASES FOR UNCONDITIONED SUBJECTS

APPENDIX G

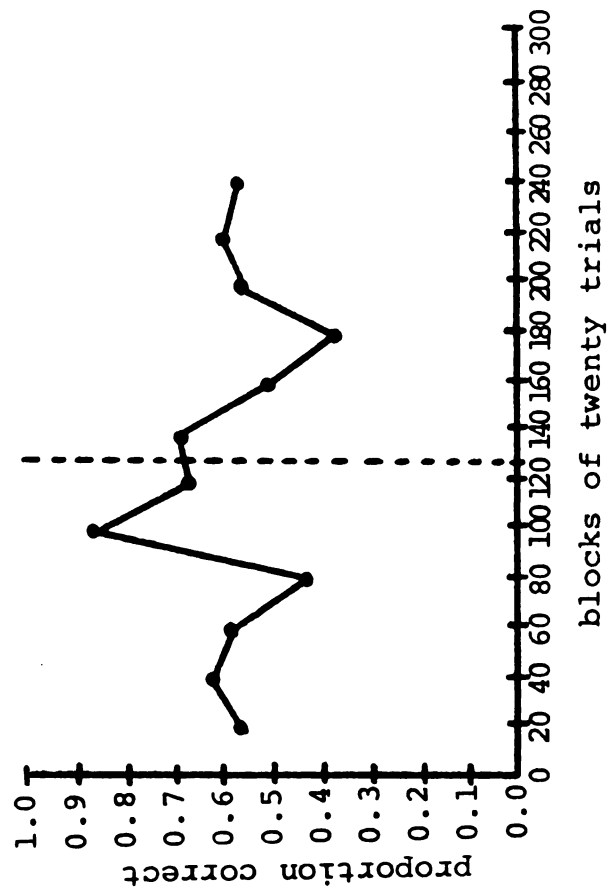


Figure G1. Conditioning Performance Across Conditioning and Test Phase for Subject 3, Experimental Condition di/ga.

APPENDIX G

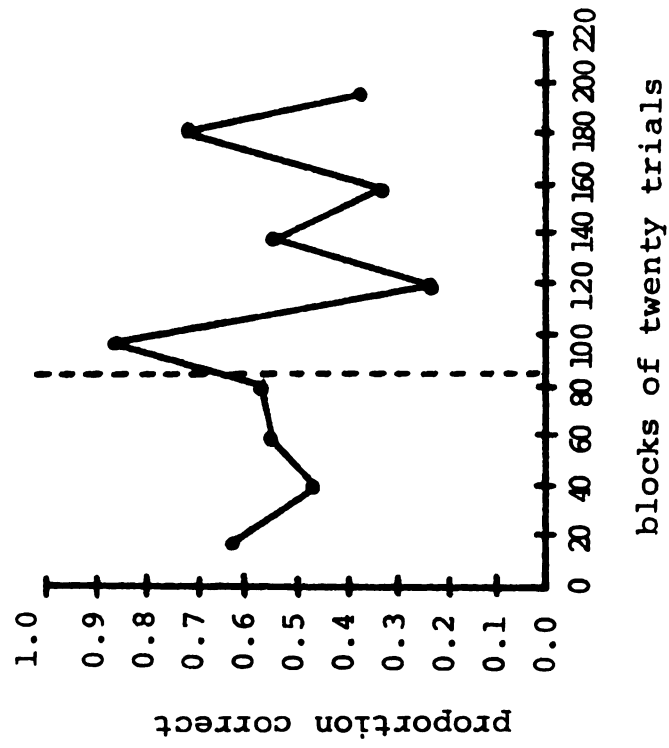


Figure G2. Conditioning Performance Across Conditioning and Test Phase for Subject 4, Experimental Condition du/ga.

APPENDIX G

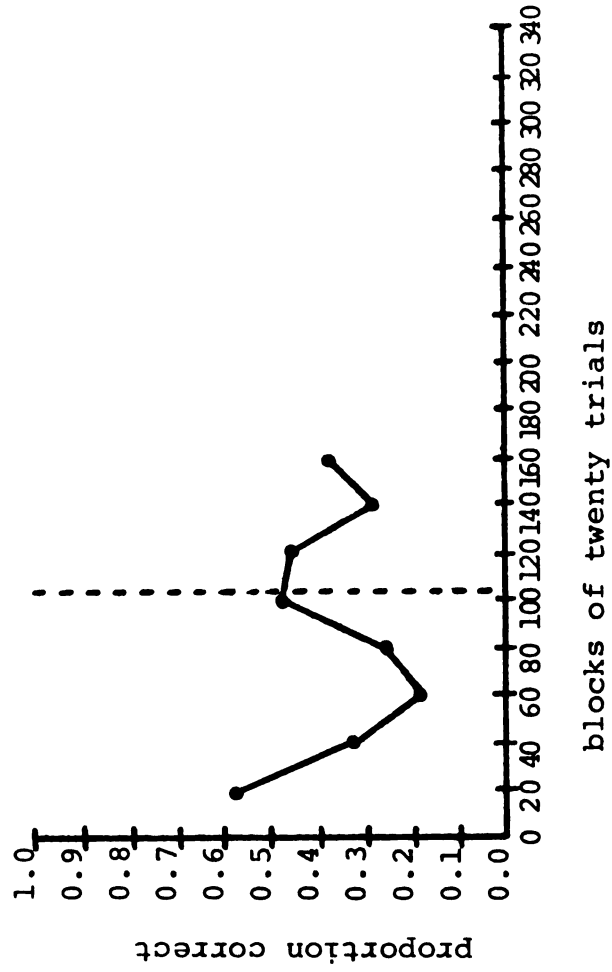


Figure G3. Conditioning Performance Across Conditioning and Test Phase for Subject 5, Experimental Condition du/ga.

APPENDIX G

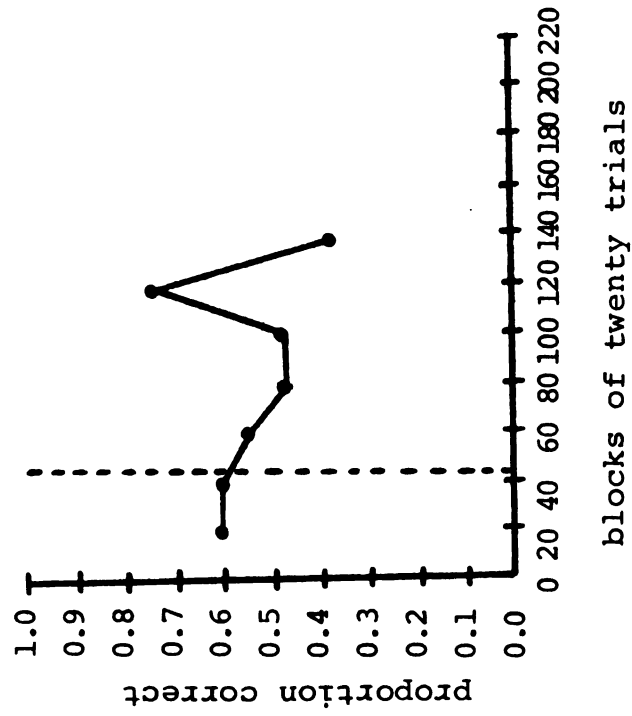


Figure G4. Conditioning Performance Across Conditioning and Test Phase for Subject 6, Experimental Condition du/ga.

APPENDIX G

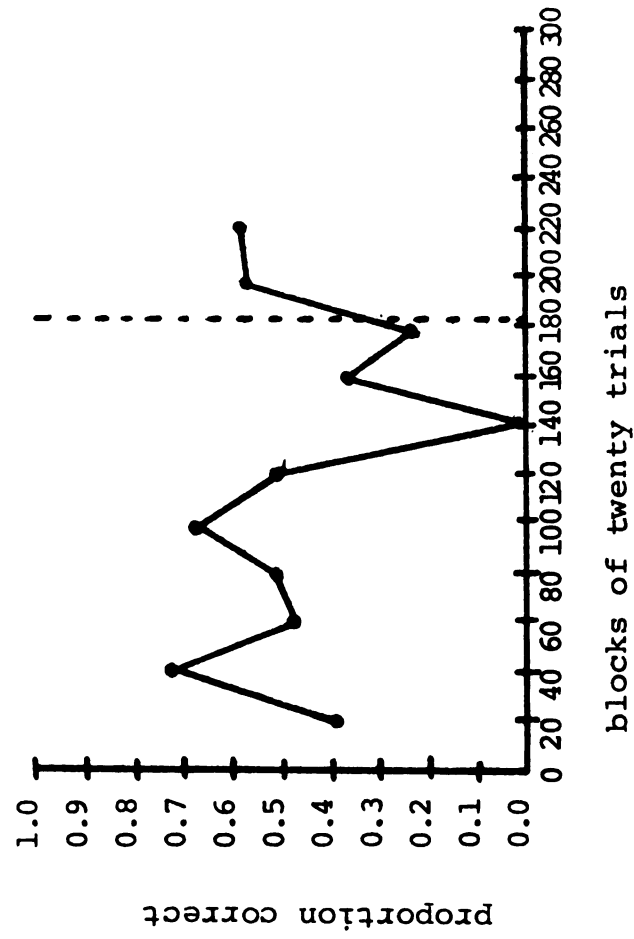


Figure G5. Conditioning Performance Across Conditioning and Test Phase for Subject 7, Control Condition di/du.

APPENDIX G

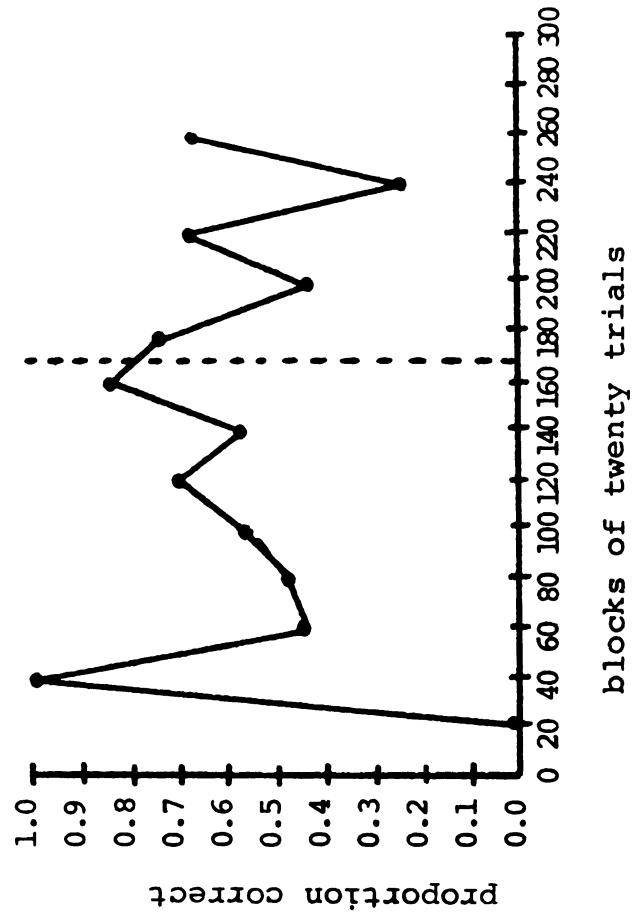


Figure G6. Conditioning Performance Across Conditioning and Test Phase for Subject 8, Control Condition di/du.

APPENDIX G

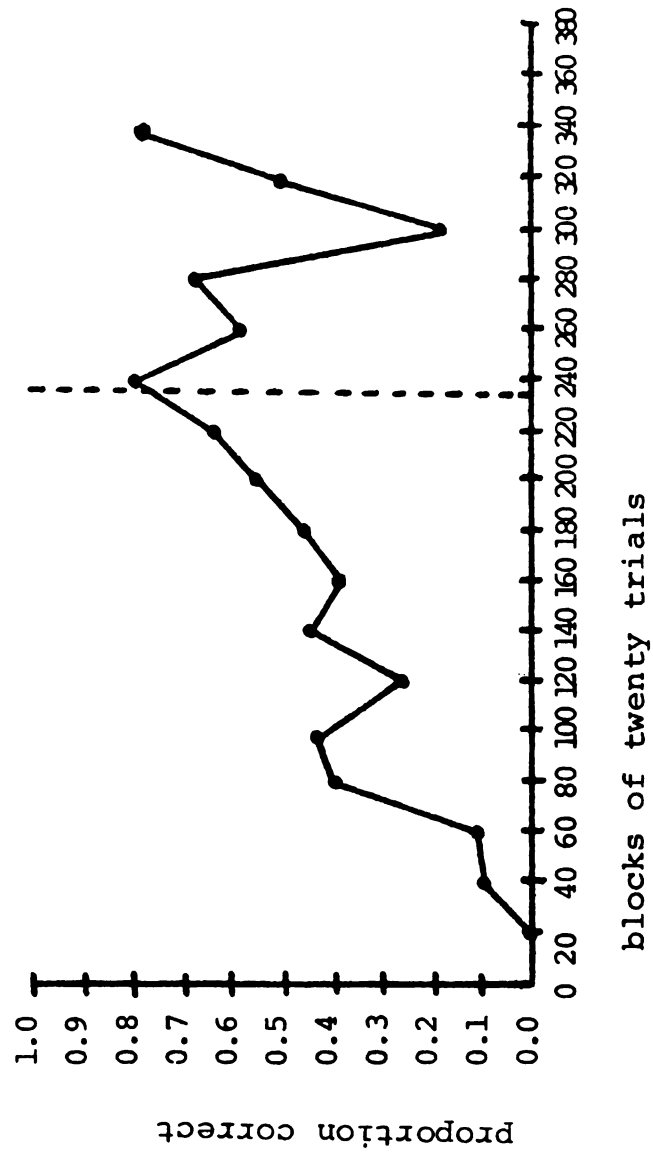


Figure G7. Conditioning Performance Across Conditioning and Test Phase for Subject 10, Control Condition di/du.

APPENDIX H

RESPONSE FREQUENCIES TO DISCRIMINATIVE STIMULI
ACROSS BASELINE CONDITIONING AND TEST TRIALS

APPENDIX H

Response Frequencies to Discriminative Stimuli Across Baseline
Conditioning and Test Trials (Trials in Blocks)

Condition	Subject	Baseline Phase (Ten-Trial Blocks)			Conditioning Phase (Twenty-Trial Blocks)				Test Phase (Twenty-Trials Blocks)		
		1	2	3	1	2	3	4	1	2	3
<u>Experimental</u>											
di/ga	1	3	5	5	6	8	3	6	11	5	13
di/ga	2	4	9	3	5	6	11	11	10	7	7
di/ga	3	7	6	6	7	7	17	12	12	13	10
<u>Experimental</u>											
du/ga	4	8	8	5	8	15	11	-	13	15	16
du/ga	5	1	1	4	6	9	6	8	15	11	5
du/ga	6	9	10	4	10	15	-	-	16	15	14
<u>Control</u>											
di/du	7	3	0	0	5	5	9	7	4	6	11
di/du	8	0	0	4	0	3	7	17	10	10	8
di/du	9	9	7	7	1	7	7	9	15	12	11
di/du	10	6	0	3	1	8	6	4	10	13	15

Mean Response: 4.6 3.8 3.9 5.4 8.8 8.4 9.0 11.4 11.0 11.5
Mean Percent Response: 46% 38% 39% 27% 44% 42% 45% 57% 55% 58%

(Note: Mean response and mean % response do not include conditioned subjects 2 and 9)

APPENDIX I

SUMMARY OF RESPONSE FREQUENCIES TO DISCRIMINATIVE STIMULI OVER CONDITIONING AND TEST PHASES

APPENDIX I

Summary of Response Frequencies to Discriminative Stimuli Over Conditioning and Test Phases

Sub- ject	Sex	Age in Months	Condition	Conditioning Phase					Test Phase						
				Total Num- ber of Trial	Rein- forced ¹ Correct	Incorrect	No response	Proportion Correct ²	Total Num- ber of Trial	Rein- forced ¹ Correct	Incorrect	No response	Proportion Correct ²		
<u>Experimental</u>															
1	M	3	di/ga	126	123	18	17	3	0.51	171	168	49	34	2	0.59
2	F	5	di/ga	60	60	16	9	0	0.64	67	65	20	6	2	0.77
3	M	5	di/ga	124	115	41	25	4	0.62	106	104	36	27	2	0.57
<u>Experimental</u>															
4	F	5	du/ga	85	84	30	22	1	0.58	125	120	45	37	5	0.55
5	M	4.5	du/ga	101	101	17	27	0	0.39	80	76	15	14	2	0.52
6	M	5.5	du/ga	40	40	16	9	0	0.64	110	100	40	26	6	0.61
<u>Control</u>															
7	M	4	di/du	181	159	33	22	20	0.60	66	58	13	9	7	0.59
8	F	5	di/du	165	158	52	25	6	0.48	109	103	24	20	4	0.54
9	F	4	di/du	155	141	41	12	14	0.77	78	71	49	20	7	0.71
10	M	3.5	di/du	236	219	41	52	12	0.44	109	108	32	23	0	0.58

¹Reinforced trials includes correct responses, corrected responses, correct responses originating from a position other than midline, and cued responses.

²Proportion of correct responses given a spontaneous head-turn to the stimulus.

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