THE ROLE OF CONSONANT AND VOWEL ACOUSTIC FEATURES IN INFANT CEREBRAL ASYMMETRIES FOR SPEECH PERCEPTION

By

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ABSTRACT

THE ROLE OF CONSONANT AND VOWEL ACOUSTIC FEATURES IN INFANT CEREBRAL ASYMMETRIES FOR SPEECH PERCEPTION

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Infants and adults show a left hemisphere advantage for discriminating consonants in speech, and a right hemisphere advantage for discriminating musical timbre. Although it is not known which acoustic properties of speech are important for a left hemisphere advantage in infants, a right ear advantage (REA), or left hemisphere superiority, is found in adult consonant processing for consonant + vowel (CV) syllables containing formant transitions. Formant transitions are speech acoustic cues important for consonants' identification, but less important for vowels. Dichotic vowel processing usually yields a nonsignificant adult REA. Condition A (Transitions Condition) of the dissertation assessed whether the adult pattern of consonant vs. vowel asymmetries for CVs containing formant transitions also occurs in three-to-four-month-old infants.

Adult dichotic studies also suggest that formant transitions may be important for an REA in nonphonetic processing, and may contribute to consonant vs. vowel phonetic asymmetries. Condition B (Transitionless Condition) investigated the role of formant transitions in

consonant vs. vowel processing in a second group of infants, using syllables containing consonant noise cues but no formant transitions.

A dichotic habituation/dishabituation procedure was used, with heart rate change as the dependent measure. In each habituation/dishabituation test, a dichotic syllable pair was presented nine times with a variable interstimulus interval ($\underline{M}_{ISI}$ = 18 sec), so that the cardiac orienting response (OR) habituated to the pair. On the tenth trial (test trial) a novel syllable was presented to one ear while the other again received its habituation syllable, to assess discrimination of the phoneme change via OR dishabituation. Differences in OR dishabituation on the test trial were determined for each stimulus type, according to which ear received the novel syllable. All infants in each condition received four tests--a left-ear and a right-ear test of consonant discrimination and of vowel discrimination. Computer-synthesized syllables were used, all highly identifiable to adults. Condition A syllables contained formant transitions in the consonant aspiration and vowel onset; Condition B syllables had the formant transitions "straightened out" to equal the frequencies of the steady-state vowel formants. Adults were also tested in each condition for comparison to the infants, since task requirements are known to affect adult asymmetries, and no previous adult dichotic habituation/dishabituation studies had been reported.

The adults, and a large subset of infants (Group H infants), showed cardiac OR habituation during the first nine trials of the tests, indicating formation of some perceptual or cognitive model for the habituation syllable characteristics. The pattern of test trial dishabituations, reflecting detection of the mismatch between the novel and habituation syllables, was as follows:

1. adults in both conditions detected the vowel changes, and did so equally well with both ears (cerebral hemispheres);
2. adults in neither condition detected the consonant changes, and this failure involved both ears (hemispheres) equally;
3. approximately half the infants who habituated in each test of Condition A clearly detected the syllable changes, regardless of ear tested or phoneme type, causing moderate group dishabituation without ear or phoneme differences;
4. the infants in Condition B who habituated detected the vowel change only with the left ear (right hemisphere), and detected the consonant change only with the right ear (left hemisphere).

The adult failure to detect consonant changes in this task contrasts with earlier findings of consonant REAs, at least for CVs containing formant transitions. The present adult findings probably reflect the necessity of phonetic processing, and left hemisphere involvement, in adults' detection of consonant changes. However, vowels are more easily discriminable, and thus may need neither phonetic coding nor left hemisphere processing.

The infant findings likely reflect left hemisphere specialization for comparison of brief, acoustically similar properties, rather than for specifically phonetic processing. Conversely, the infant's right hemisphere appears to be specialized for comparison of slightly longer-duration, less acoustically similar properties of auditory stimuli. Discriminations which may be based either on brief, similar

acoustic cues, or on longer, dissimilar cues, lead to equal probability of processing by either hemisphere. Furthermore, the infant results may be explained by a subcortical mechanism which unilaterally activates either hemisphere dependent on the amount of acoustic discrepancy between the inputs to the two ears (brief, similar vs. longer, dissimilar portions of dichotic discrepancy). The possible relationship of the proposed infant cerebral asymmetry mechanisms to lateralized brain development was considered.

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INTRODUCTION

An extensive body of data collected over the last century has established that in humans the left and right cerebral hemispheres show differences in their level of ability to perform various cognitive functions (e.g., Milner, 1970; Piercy, Hécaen & Ajuriaguerra, 1960; Rizzolati, Umilta & Berlucchi, 1971). This phenomenon has been called hemispheric specialization, cerebral lateralization, and hemispheric or cerebral asymmetry. Clinical studies of individuals with unilateral cortical damage or severed corpus callosum, and various psychophysical studies of the neurologically intact, indicate that the left hemisphere in nearly all right-handed adults is dominant in language processing, speech production, and language-related skills such as writing and reading (Branch, Milner & Rasmussen, 1964; Geschwind, 1970; Kimura, 1961a, b, 1967; Kimura & Folb, 1968; Luria, 1970; McAdam & Whitaker, 1971; McKee, Humphrey & McAdam, 1973; Milner, 1962, 1969; Milner, Taylor & Sperry, 1968; Morrell & Salemy, 1971; Springer, 1971). In contrast, the right hemisphere is dominant for performing tasks that involve musical perception or spatial abilities (Benton, 1972; Curry, 1967; Deutsch, 1975; Durnford & Kimura, 1971; Fontenot & Benton, 1972; Hebb, 1939; Harris, 1975; Kimura, 1963a, b, 1964, 1969; Levy, 1976; Luria, Simernitskaya & Tubylevich, 1970; McDonough, 1972; Nebes, 1971; Shankweiler, 1966; Teuber, 1962; Harris & Best, Note 1).

Assessment of Auditory Cerebral Asymmetries Through Dichotic Listening Tests

The dichotic listening test is one of the most useful methods developed thus far for assessing auditory cerebral asymmetries in both clinical and normal populations (e.g., Kimura, 1961a, b, 1967). In a typical dichotic test trial, each ear receives a different stimulus simultaneously through dual-channel headphones. The subject must either recall what he heard, or identify the components of the dichotic stimulus pair from among a set of binaurally presented choices. Because the contralateral ear-to-brain connections are stronger than the ipsilateral connections in mammals (Darwin, 1974; Hall & Goldstein, 1968; Rosenzweig, 1951; Tunturi, 1946), and clinical evidence indicates that dichotic stimulus competition minimizes ipsilateral ear-to-brain transfer (Kimura, 1961a, b, 1967; Milner, Taylor & Sperry, 1968), a significant ear advantage in performance is commonly interpreted as reflecting that the contralateral hemisphere was dominant or more proficient than the ipsilateral at the task.

Alternative explanations have been offered that dichotic ear advantages are the result of asymmetries in the attention the individual directs toward the inputs from the two ears, or are the result of task-imposed asymmetries in cortical activation and/or attentional processes. The suggestion that voluntarily-controlled strategies for directing unilateral attention to either ear are the basis for dichotic ear advantages has been inconsistently supported. In some cases, the degree of ear asymmetry for verbal stimuli has been affected by task instructions that were designed to induce subjects to direct their attention to either the right or left ear (e.g., Haydon & Spellacy, 1973; Oxbury,

Oxbury & Gardner, 1967; Spellacy, 1969; Treisman & Geffen, 1968; Treisman & Riley, 1969); in other cases, voluntary attentional strategies have failed to affect the degree of ear asymmetry for verbal stimuli (e.g., Inglis & Sykes, 1967; Porter & Berlin, 1975; Myers, 1970). However, there is a fair amount of theoretical and experimental support for the hypothesis that an ear advantage reflects largely involuntary, task-induced activation of the contralateral hemisphere (e.g., Hiscock & Kinsbourne, 1977; Kinsbourne, 1970, 1973, 1974, 1975; Curcio, Note 2; Hiscock, Note 3). The proposition that ear asymmetries reflect unilateral cortical activation/attention is not necessarily at odds with the more popular interpretation that an ear advantage results from the processing superiority or dominance of the contralateral hemisphere.

In dichotic studies, a right ear advantage (REA) typically has been found in verbal auditory tasks, reflecting left hemisphere specialization or activation, and a left ear advantage (LEA) has been found in nonverbal auditory tasks, reflecting right hemisphere specialization or activation. The verbal speech stimuli used need not be linguistically meaningful, or "natural," to yield a right ear advantage. For example, when the speech stimuli used in a dichotic test are nonsense syllables rather than meaningful words, an REA is still obtained (e.g., Myers, 1970; Shankweiler, 1971; Spellacy & Blumstein, 1970; Studdert-Kennedy & Shankweiler, 1970). Furthermore, when natural speech sounds are played in reverse on a tape recorder, and used in a dichotic test paradigm, a significant REA is again obtained (Kimura & Folb, 1968), even though the stimuli sound "unnatural."

The Ontogeny of Cerebral Asymmetries in Audition

Adult left hemisphere specialization for language and for analysis of speech stimuli, which need not be semantically meaningful, implies that there is some biological bias toward development of left hemisphere dominance for language abilities. Likewise, the consistency of right hemisphere dominance in adults for nonspeech auditory processing and visuospatial abilities implies some bias toward development of right hemisphere specialization. In fact, the findings on adult cerebral asymmetry provide evidence for a "speech-nonspeech" distinction in auditory perception, whose development most likely has a biological basis. These suggestions lead one to ask what mechanisms underlie the development of cerebral asymmetry, and at what points in the course of normal development the biases toward hemispheric specialization and a "speech-nonspeech" distinction become evident.

Lenneberg (1969) has been a strong proponent of the theory that the development of language is biologically based, being tied to brain maturation. He postulated that left hemisphere language bias is not evident until two years of age in normal children, after which cerebral lateralization grows in strength until it is well-established in early adolescence. This hypothesis was based on clinical evidence that children are much better able than adults to acquire or recover language functions after left hemisphere damage (Basser, 1962). Furthermore, according to Lenneberg's model, up to early adolescence the amount of the child's language recovery following left hemisphere damage decreases as the age at injury increases. Young children, according to Basser's report, are equally likely to show some language disturbance after either right or left hemisphere damage, whereas adults and older children are much more likely to show language disturbance after left than after right hemisphere damage.

A broader and more careful look at the clinical developmental literature, however, suggests that left hemisphere damage more often delays or otherwise disturbs language development than does right hemisphere damage, even in young children (e.g., Aicardi, Amsili & Chevrie, 1969; Alajuoanine & Lhermitte, 1965; Annett, 1973; Byers & McLean, 1961; Hécaen, 1976; Kinsbourne, 1975; Taylor, 1883). The incidence of childhood right-hemisphere related speech disorders appears to have been overestimated by Lenneberg and by Basser (see Kinsbourne, 1975; and discussion by Entus, Note 4). In addition, studies of individuals with unilateral brain damage in early infancy have revealed the adult pattern of cerebral asymmetries in the subtle but persistent selective deficits that are related to the side of injury. Those individuals with early left hemisphere damage have lower verbal IQ scores and language abilities than normal control subjects or those with right hemisphere damage; those with right hemisphere damage have lower than normal spatial abilities and nonverbal IQ scores (Dennis & Kohn, 1975; Dennis & Whitaker, 1976; Kohn & Dennis, 1974; McFie, 1961; McFie & Thompson, 1971; Rudel & Teuber, 1974; Smith, 1976; Teuber, 1970). Reports that children with early left hemisphere damage often develop or retain left hemisphere language, unless there has been severe speech area damage, provide further clinical support for very early functional lateralization (Milner, 1974; Rasmussen & Milner, 1977).

Dichotic Listening Tests with Non-brain-damaged Children

Recent developmental studies of cerebral asymmetries in non-clinical populations of children also have yielded inconsistent findings with regard to the earliest age at which a significant REA for verbal and speech stimuli can be found, and with regard to evidence of developmental changes in strength of cerebral asymmetry. In the first developmental test of dichotic listening abilities in children, ranging in age from four to nine years, Kimura (1963b) found an REA for recall of digits at all ages, without a significant change in degree of REA over age. She replicated this finding with a group of five- to eight-year-old children of somewhat lower socio-economic status than the group tested in the earlier study (Kimura, 1967). Others have since replicated these findings, including the lack of age change in strength of asymmetry in verbal dichotic tests (Bryden, 1970; Hiscock & Kinsbourne, 1977; Mirabile, Porter, Hughes & Berlin, 1978; Nagafuchi, 1970). A verbal REA has been found in children as young as two-and-a-half (Bever, 1971) or three years (Hiscock & Kinsbourne, 1977). Also, in preschool children the speed of right-index-finger tapping is more diminished by concurrent speech than is left finger tapping speed, which implies that left hemisphere dominance for speech production at that age interferes with the left hemisphere control of the right hand (Kinsbourne & McMurray, 1975). Specialization of right hemisphere functions in dichotic listening has also been found in children. In a dichotic test for recognition of animal sounds by five- to eight-year-old children, a significant LEA was found at all ages (Knox & Kimura, 1970).

Although the studies just cited suggest early left hemisphere language lateralization without a significant age change in degree of lateralization for normal children, other studies suggest some age change in amount of lateralization for other populations of children. A dichotic test with verbal stimuli revealed an REA by at least five or six years in normal children, but no significant REA at that age for language-delayed children (Sommers & Taylor, 1972). Another study of language-disturbed children with auditory-linguistic deficits suggests that they have left hemisphere speech area dysfunctions that affect their dichotic ear asymmetry scores, and that the dysfunction may have caused reversed lateralization in some (Witelson & Rabinovitch, 1972). Socioeconomic class also affects ear asymmetries, since in several tests of four- to nine-year-olds from several countries, middle- to upper-class children showed a significant REA at all ages, while the lower class children only showed an REA by about age seven (Dorman & Geffner, 1974; Geffner & Hoffman, 1971; Pizzamiglio & Cecchini, 1971).

In contrast with the earlier-discussed studies of normal children, moreover, some recent dichotic research with normal children has found suggestions of age changes in strength of lateralization for auditory processing. In a dichotic test for recall of lists of digits by five- to eleven-year-old Dutch children, right-ear scores increased with age and a significant REA was found only by age nine (Satz, Bakker, Teunissen, Goebel & Van der Vlugt, 1975). The level of difficulty was manipulated in another dichotic digit recall test by variations in the length of the dichotic list of digits that was to be recalled by five- to ten-year-old children. In that study, an REA was found only for the most difficult task, recall of three dichotic pairs of digits, and this REA was evident only by age nine (Inglis & Sykes, 1967). An additional dichotic digit recall test, this time with Canadian second, fourth, and sixth graders, indicated that there was an overall REA at all ages, but that the proportion of subjects with a significant REA was only substantially different from the proportion of subjects with an LEA by sixth grade (Bryden & Allard, 1977). An REA was found only by fourth grade for girls, and only by sixth grade for boys, in a dichotic nonsense CV recall test of children in kindergarten through eighth grade. In that study, the proportion of subjects showing an REA versus those showing an LEA only reached the adult ratio by eighth grade (Bryden, Allard & Scarpino, 1973).

Throughout most of this developmental research on cerebral asymmetries the implicit assumption seems to have been that cerebral asymmetry is a global trait that could be tapped by any valid dichotic listening test (as evidenced by the variety of stimuli, procedures, scoring and analysis methods used by different researchers), and the search seemed to be primarily for the most valid dichotic test to use with children of different ages. A major deficit in this research has been the failure to equate task difficulty for children of different ages, and failure to adjust ear difference scores to account for floor and ceiling effects. Recently, however, it has been suggested that different aspects or levels of auditory processing may differ in the age at which they first exhibit an REA, and may also differ in amount of change in strength of cerebral asymmetry with age (Bryden & Allard, 1977; Porter & Berlin, 1975; Best & Glanville, Note 5). These different aspects or levels of auditory stimulus processing may include auditory/phonetic analysis, versus auditory preperceptual echoic memory, versus auditory short-term memory of stimulus parameters, versus memory of temporal order of components in a stimulus set or in a multipartite stimulus, versus semantic processing, etc. Moreover, it has also been suggested that lateralization *per se* does not develop with age; instead, general age changes in quality of information processing and overall performance on various tasks may affect dichotic asymmetries without actually implying a change in strength of lateralization (Kinsbourne, 1975). Differences in dichotic ear asymmetries among children of various ages and background characteristics may reflect performance differences related to general cognitive/perceptual level, motivation, processing strategies (e.g., verbal or nonverbal problem-solving), or attention, rather than reflecting true differences in degree of lateralization. Unless statistically partialled out, overall performance is confounded with the degree of laterality on a test (Richardson, 1976).

The Necessity of Predisposing Factors Toward Cerebral Asymmetry in Infancy

Regardless of evidence for the earliest age at which an REA is found in tests of children with dichotic verbal or speech stimuli, and evidence of age changes in strength of asymmetry, there must logically be some predisposing factor toward left hemisphere language development before even age two. The normal and clinical developmental literature on cerebral asymmetry, and the consistency in direction of lateralization found in adults, suggest that organization for left hemisphere language specialization begins in infancy, perhaps long before the functional level of cerebral asymmetry noted by Lenneberg. Findings that the left planum temporale (a major speech processing area in the auditory cortex) is larger on average than the right in infant brains as young as twenty-nine gestational weeks (Wada, Clark & Hamm, 1975; Witelson, 1975; Witelson & Pallie, 1973), as is the case for adults (e.g., Geschwind & Levitsky, 1968), support the suggestion that there may be early left hemisphere specialization for auditory processing which relates to language.

The anatomical asymmetries in infant speech processing areas suggest that infants may also show some behavioral evidence of left hemisphere specialization for auditory processing. If there are several aspects or levels of auditory stimulus processing that show age changes in degree of hemispheric specialization, one would most likely expect simple auditory-acoustic or phonetic processing to show earliest evidence for lateralization. This contention is supported by recent studies of cerebral asymmetry for auditory processing by young infants. For infants as young as a few days of age, the auditory evoked response (AER) is greater over the left than over the right hemisphere during the presentation of speech stimuli, presumably reflecting greater left hemisphere activity and therefore left hemisphere dominance. Conversely, the AER is greater over the right hemisphere than over the left during the presentation of nonspeech auditory stimuli, supposedly reflecting right hemisphere dominance in processing (Molfese, Freeman & Palermo, 1975; Molfese, Nunez, Seibert & Ramaniah, 1976). These findings generally parallel the results found in AER studies of adults (e.g., McAdam & Whitaker, 1971; McKee, Humphrey & McAdam, 1973; Molfese, Freeman & Palermo, 1975), and thus mirror the adult pattern of cerebral asymmetry in cortical neural response to auditory stimuli. Those findings were extended by Entus (Notes 4 & 5) in a dichotic habituation/dishabituation study of young infants, which used high amplitude sucking rate as the dependent measure. The two- to five-month-old infants in her study displayed an REA for discrimination of phonemic change in nonsense CVs, and an LEA for discrimination of a change in the timbral quality of musical notes (that is, a change in the type of instrument playing a note of the same pitch). In another dichotic habituation/dishabituation study of three-month-old infants, which used heart rate as the dependent measure and variable 25 second ISIs, evidence was found for an REA in short-term auditory memory for consonants in nonsense CVs, and an LEA in short-term auditory memory for the timbral quality of musical notes (Glanville, Best & Levenson, 1977; Best & Glanville, Notes 6 & 7; Glanville, Best & Hoffman, Note 8).

These infant cerebral asymmetries generally mirror the adult pattern of asymmetries, as noted earlier, and provide evidence that at some level young infants distinguish between speech and nonspeech, and process the two stimulus types differently. However, the mechanisms by which they make the "speech-nonspeech" distinction and thus show differential hemispheric processing for the two stimulus types are as yet unknown. Also, the acoustic properties of the two types of signal that may be important for their distinction and differential hemispheric processing by young infants are still not known.

Encodedness and the REA for Phonetic Processing

Dichotic listening studies of adult speech perception suggest some possibilities for the way in which infants may be able to make a "speech-nonspeech" distinction and show the adult pattern of cerebral asymmetries in auditory perception. The adult literature indicates that not all speech sounds indeed produce an REA in a dichotic listening test, even when the task involves phonetic processing. Certain portions of the acoustic speech signal that are considered to be highly encoded produce an REA, whereas portions of the speech signal that are considered relatively unencoded do not produce an REA. Encodedness refers to the fact that in normal speech, the specific acoustic properties associated with a given phoneme are to some extent context-conditioned by the acoustic properties of the adjacent phonemes, and therefore show acoustic variation in different phonemic environments. Highly encoded phonemes show fairly high variance in their acoustic parameter values depending on the phonemic context in which they are found. In other words, the phonetic identity of the phoneme does not show a simple one-to-one correspondence with its acoustic properties in various phonemic contexts. Its identity is instead "encoded" in the acoustic signal, and must be "decoded" from the acoustic information rather than simply matched to an invariant acoustic template. Unencoded phonemes, on the other hand, show very little context-conditioned variance in the acoustic parameters that are important for identifying them (Liberman, Cooper, Shankweiler & Studdert-Kennedy, 1967). A consistent finding in adult dichotic phonetic identification tests, which have used nonsense CV syllables as stimuli, has been a strong REA for identification of stop consonants. Stop consonants (/b/, /d/, /g/, /p/, /t/, /k/) are the most highly encoded phonemes in our language, according to the description of encodedness just presented. In the same dichotic studies, nonsignificant REA has been found for adults' identification of vowels, which are considered unencoded (e.g., Shankweiler, 1971; Shankweiler & Studdert-Kennedy, 1967; Studdert-Kennedy & Shankweiler, 1970).

It may be that degree of encodedness in speech sounds also affects differential hemispheric processing of speech stimuli by infants. Highly encoded segments of the speech signal may be more likely than unencoded segments to elicit an REA in dichotic discrimination tests of infants, as they do in adults. However, the way infants process the speech sounds may differ qualitatively from the way adults do, and encodedness mav affect differential hemispheric processing by infants in a different manner than it affects adult cerebral asymmetry in speech perception. Encodedness by its definition refers to the way in which adults assign a phonetic label to the acoustic speech signal.

Encodedness, Categorical Perception, and Phonetic Processing in Adults and Infants

Adults perceive encoded speech sounds (consonants) categorically, according to the phonetic labels they assign to them. This means that although the acoustic parameter that is important for distinguishing between two speech sounds (e.g., the difference between voiced vs. voiceless stop consonants, /p/ & /b/, is determined by Voice Onset Time following the initial consonant noise production) can be varied along a continuum, adults discriminate the sounds only so well as they can apply different phonetic labels to them. They do not discriminate acoustic differences within a phonetic category even though the degree of within-category acoustic difference may be as great as the acoustic difference they can discriminate between categories. Dichotic studies show that adults have a left hemisphere advantage for processing sounds that they perceive categorically, whether speech or nonspeech (e.g., Cutting, Note 9). Adults neither perceive vowels categorically, nor show an REA for them, presumably because vowels are relatively unencoded.

Infants as young as one month also discriminate encoded speech sounds (consonants) categorically, usually according to the same acoustic-phonetic categories adults show (e.g., Eimas, 1974a, b, 1975a; Eimas, Siqueland, Jusczyk & Vigorito, 1971; Jusczyk, 1977; Moffitt, 1971; Morse, 1972, 1974; Trehub & Rabinovitch, 1972). Also, like adults they perceive vowels noncategorically, or continuously, in that they discriminate within-category as well as between-category acoustic differences (Swoboda & Morse, 1976). For /l/ and /r/, which are more encoded than vowels but less encoded than stop consonants, infants as well as adults show an intermediate degree of categorical perception (Eimas, 1975a, b). The parallels between adult categorical perception of encoded speech sounds and infant categorical speech perception have led many researchers to propose that infants process speech in a linguistic or phonetic manner, via a specialized speech processor of some sort that may be similar to those proposed for adults (e.g., Eimas, 1974a, b, 1975a, b; Eimas, Siqueland, Jusczyk & Vigorito, 1971; Miller & Morse, 1976; Moffitt, 1971; Morse, 1972, 1974).

Several investigators have recently argued, however, that no evidence is yet available for rejecting an equally plausible and more conservative interpretation that infants process speech sounds according to their acoustic properties rather than their phonetic identities, and do not necessarily possess a specialized phonetic speech processor (e.g., Cutting & Eimas, 1974, 1975; Stevens & Klatt, 1974; Studdert-Kennedy, 1974). If the latter interpretation is true, then the phonetic identity of speech signals would not be important in the infant's response to the signals. In that case, the property of encodedness as defined earlier would not affect differential hemispheric processing by infants. It may be that infants would show no difference in cerebral asymmetry for discrimination of consonants versus vowels, or that any difference in cerebral asymmetry for those two types of speech stimuli in infants depends on their acoustic properties *per se* and not on the degree of encodedness of their phonetic identities.

A Test of Differential Hemispheric Asymmetries In Infants For Consonant and Vowel Processing

Condition A of the dissertation research study determined whether a group of three-to-four-month-old infants, like adults, display a significant REA for discrimination of consonants in CV syllables, and at the same time fail to show an REA for discrimination of vowels in CV syllables. A dichotic habituation/dishabituation procedure was used, with change in heart rate as the dependent measure. In this procedure a dichotic syllable pair (e.g., /pa/-/ta/) was presented repeatedly (nine times) to the infant over dual-channel headphones, with a variable 18 second ISI, until the cardiac orienting response (OR) was expected to have habituated. The cardiac OR, which is a phasic decrease or deceleration in heart rate (or an increase in heart period or interbeat interval), is consistently interpreted as a reflection of preparation to attend for intake of stimulus information (e.g., Lacey, Kagan, Lacey & Moss, 1962; Lacey & Lacey, 1970). After the cardiac OR habituated to the original dichotic syllable pair, a test trial was run in which a novel test syllable was presented to one ear while the other ear again received its habituation stimulus (e.g., /pa/ - /ka/). To measure discrimination of the novel test stimulus from the original habituation stimulus for the same ear, recovery of the OR on the test trial was assessed, relative to the cardiac response level on the last habituation trial of that test sequence. Ear differences were determined according to the ear receiving the novel test stimulus. This technique has been successful in other tests of three-month-old infants (Glanville, Best & Levenson, 1977; Best & Glanville, Note 6) as well as two- and four-month-olds (Best & Glanville, Note 7; Glanville, Best & Hoffman, Note 8). All infants received four tests: a left-ear test and a right-ear test for discriminating a change in the consonant of CV syllables, and a left- and a right-ear test for discriminating a change in the vowel in CV syllables.

The experimental condition just described was designed to determine whether young infants show left hemisphere dominance in processing those parts of the speech signal which have been defined in the adult speech perception literature as highly encoded, in contrast to showing a lack of hemispheric specialization in processing those parts of the speech signal which have been defined in the adult literature as unencoded. If degree of encodedness is associated with differences in degree of REA for infants as it is for adults, the prediction was that the infants tested would show an REA for the consonant discrimination tests, but no ear difference for the vowel discrimination tests.

According to the available data on infant dichotic listening, it was already known young infants show an REA for discrimination among some consonant sounds (the change discriminated in the following studies was a change in consonant acoustic characteristics: Glanville, Best & Levenson, 1977; Best & Glanville, Notes 6 & 7; Entus, Notes 4 & 5; Glanville, Best & Hoffman, Note 8). There had not yet been any studies of infant cerebral asymmetries in vowel discrimination. However, even if the infants showed the predicted difference in cerebral asymmetry for processing the two stimulus types, the reason that they showed that difference would still be unclear. It would not necessarily follow from the predicted results for Condition A that the phonetically relevant property of encodedness (that is, the association of a phonetic identity with the acoustic properties of the speech signal) produced any of the possible differences in degree of REA. It seemed clear that if there were a difference in amount of infant cerebral asymmetry for processing consonants versus vowels, it may not have resulted from phonetic processing by the infants, but may instead have resulted from auditory, non-phonetic processing of the acoustic features in the speech signal. In fact, whether infant cerebral asymmetries for speech perception resulted from either phonetic or purely auditory processing, the acoustic properties of speech that are important for infant cerebral asymmetries would still not be known.

Acoustic Features of Speech and the Adult REA: Formant Transitions

Dichotic listening studies of speech perception in adults suggest that rapidly changing spectral characteristics of acoustic stimuli, such as the formant transitions in speech, may be important acoustic cues leading to a left hemisphere dominance in auditory processing. The formant transitions are sets of simultaneous brief frequency glides found in natural speech between the steady-state acoustic information associated with consonants and the steady-state frequency bands (formants) associated with vowels. These frequency transitions occur within the aspirated portions of aspirated consonants (e.g., /p/) that follow the steady-state consonant noise information, and in the initial portions of the formants associated with vowels (for spectrographic illustrations of these acoustic properties, plotted as a function of frequency against time, see Figures 2 and 3, in METHOD and Figures D1 and D2, in Appendix D). They result from the movements of the oral articulatory processes as the speaker shifts between consonant and vowel production (or, in the case of diphthongized vowels, as the speaker shifts from production of one vowel to another).

Formant transition cues play a major role in adult listeners' identification of most, if not all, consonants. They are not essential cues for the identification of vowels, and play a much smaller role in vowel than consonant perception in nonsense CVs (Stevens & Klatt, 1974). This information is relevant to the issue of which acoustic cues in speech are associated with an REA in dichotic listening tests with nonsense syllables. Stop consonants, which are cued primarily by rapid formant transitions, show a large REA in adults, while liquids

(/l/, /r/), which are cued partially by slower formant transitions and partially by steady-state formant frequency information, exhibit a smaller REA. Vowels, which are identified primarily by their steady-state formant frequency values and have very slow transitions or none at all, elicit a nonsignificant REA (Cutting, 1974a, b; Day & Vigorito, 1973; Shankweiler, 1966; Shankweiler & Studdert-Kennedy, 1967; Studdert-Kennedy & Shankweiler, 1970).

The findings just discussed suggest that the left hemisphere in adults may be specialized not only for linguistic and phonetic analysis, but also for some sort of specialized auditory analysis of transient, temporally changing acoustic features such as the formant transitions. This suggestion is supported by several recent studies. Identification of the consonants in fricative (/f/, /s/, /ʃ/, etc.) + vowel syllables elicit an REA when the syllables contain formant transitions between the frication (a steady-state, band-limited noise burst associated with fricatives) and the steady-state vowel, as is the case in natural speech. However, when the formant transitions are removed from those syllables, identification of the fricative does not produce an REA, even though the syllables still sound like fairly normal speech and the phonemes are still highly identifiable (Darwin, 1971, 1974). Furthermore, synthetic speech-like stimuli (i.e., with several wide-band formants in the speech frequency range) that begin with phonetically impossible formant transitions (at least in English) produce an REA for identifications of the initial transitions, even though they cannot be <u>phonetically</u> identified (Cutting, 1974a, 1974b). Other nonspeech auditory stimuli containing formant transitions (Cutting, 1974b), or some other sort of transient, rapidly-changing acoustic information that is important for the solution of a given dichotic task, may also produce an REA (Halperin, Nachson & Carmon, 1973; Cutting, Note 9).

Possible Role of Neural Responses in Auditory Feature Analysis of Speech

The data just cited provide evidence for a hemispheric asymmetry in auditory feature analysis of speech and some nonspeech auditory stimuli. In fact, one would expect to find specialization for auditory feature analysis of this sort relevant to the acoustic properties of speech, given the special nature of speech and speech perception (see discussions by Marler, 1977; Studdert-Kennedy, 1974). This proposed specialized auditory analysis of speech may be mediated by specialized acoustic trigger feature analyzers, which are neurons or neuron networks in the auditory system that respond selectively to complex acoustic features of auditory stimuli. They are referred to as feature analyzers rather than feature detectors to denote the complex rather than simple nature of the auditory analysis they perform. The term "trigger" is used to denote that the phenomenon under discussion is a neural rather than a perceptual/cognitive event, since the term "feature detector" as currently used in the neurophysiological literature implies the latter phenomenon (e.g., Weisstein, Note 10; Zacks, Note 11).

That is, the neural trigger response to stimulus features may not correspond to the perception of the totality of a complex stimulus, but may instead respond to a particular stimulus component, and only in the context of the complete stimulus. For example, repeatedly presenting adults with a /p/ will shift the /p/-/b/ category boundary in a subsequent categorical perception discrimination study, suggesting adaptation of a neural feature trigger to the /p/ percept. However, the post-adaptation boundary shift generalizes to the /t/-/d/ phonetic distinction, even though there was no exposure to /t/ during adaptation, indicating that the neural trigger response was related to the stimulus component of voicelessness (long voice onset time, or VOT) and not to the phonetic percept /p/. Furthermore, this adaptation effect does not occur if the subjects are adapted only to the isolated acoustic component associated with a phonetic distinction; the entire phonetic stimulus must be presented during adaptation (e.g., Eimas & Corbit, 1973; Miller, 1975).

Neurophysiological trigger studies with mammals other than humans have revealed complex feature analyzers in both the visual cortex (e.g., Hubel & Wiesel, 1962, 1965; Poggio, 1972; Riggs, 1971; Stone, Note 12), and the auditory cortex (e.g., Altman, 1968; Evans, 1974; Evans & Whitfield, 1964; Nelson, Erulkar & Bryan, 1966; Suga, 1964). Some of the auditory trigger feature analyzers that have been found respond selectively to a particular species-specific vocalization, and show a much-reduced response that is often changed in form, or completely lost, when portions of the vocalization are deleted (Evans, 1974; Wollberg & Newman, 1972). It has been suggested that there are also likely to be acoustic trigger feature analyzers in the human auditory system, which are specifically tuned to complex acoustic features inherent in speech, such as the formant transitions (Abbs & Sussman, 1971). Such feature analyzers may be involved in the simultaneous detection and weighted tracking of the formant transitions (for discussions of this possibility and its relevance to phonetic processing, see: Ades, 1974a, b; Bailey, 1973; Cooper, 1974; Cooper & Blumstein, 1974; Miller, 1975; Studdert-Kennedy, 1974).

The suggestion that there may be neural feature detectors in the human auditory system, specifically tuned to phonetic features of speech, associated with phonetic percepts, and fatiguable by selective adaptation, has been supported by data showing that selective phonetic adaptation causes boundary shifts in adults' categorical perception of encoded speech stimuli (as in the example cited two paragraphs ago--e.g., Cutting, 1974a; Eimas & Corbit, 1973; Miller, 1975). Recent research suggests, however, that phonetic category boundary shifts can be produced by many fewer stimulus presentations than would be needed to adapt or fatigue a feature detector, suggesting that the "adaptation effects" are really acoustic contrast effects. These recent data have led to the argument that there are not likely any phonetic feature detectors underlying adult speech perception (e.g., Simon & Studdert-Kennedy, Note 13).

The distinction made earlier between feature detectors and feature triggers is relevant here. If the so-called adaptation effects are reflections of acoustic contrast detection rather than of fatigued feature detectors, then there is indeed no support for phonetic feature detectors. But the notion that there are trigger feature analyzers for acoustic components of complex phonetic stimuli is not upset by a failure to establish that category boundary shifts result from neural fatigue, since contrast effects are part of the nature of trigger feature analyzers. Therefore the latter neural mechanisms cannot yet be rejected as an integral part of adult speech perception, and it is proposed here that they are probably a lower-level component of a hierarchy for speech signal processing by adults. Acoustic trigger feature analyzers such as those proposed may be operating in infancy, and in fact may be a mechanism by which infants show differential hemispheric processing of auditory stimuli.

A Test of the Role of Formant Transitions in Infant Acoustic Feature Analysis of Dichotic Consonants and Vowels

Condition B of the dissertation research study was designed to determine whether formant transitions are necessary for speech stimuli to produce an REA in infant dichotic speech perception, particularly for consonant discrimination. The same dichotic test procedure and syllables used in Condition A were used to test a second group of three-to-four-month-old infants. However, in this second condition the formant transitions of all the syllables were "straightened out" to equal the steady-state frequency values of the vowel formants, so that only the steady-state consonant cues (i.e., burst and frication cues, since voiceless stops and fricatives were used in the syllables for this study) were available in the syllables for discriminating among the consonants, and only steady-state cues for vowel discrimination. The prediction was that if the formant transitions play a major role in producing an REA in infant dichotic acoustic perception of speech, then there would be no ear difference in discrimination either of a change in the consonant in the CV syllables or of a change in the vowel in the syllables.

However, acoustic properties other than frequency transitions may be important in infant cerebral asymmetries for auditory stimuli, leading to alternative results. For example, discrimination of steady-state vowels by infants may be based on detection of differences between the vowels in the relationships among the formant frequencies. Music timbre discrimination by infants, which is probably based on detection of differences between musical notes in the relationships among steady-state frequency components, produces an LEA in infants. Thus an alternative possibility was that infant discrimination of steady-state vowels in Condition B would produce an LEA.

Conversely, an alternative possibility regarding discrimination of transitionless consonants was that infants might show an REA for processing any brief, transient acoustic properties rather than just for processing frequency transitions. Infant discrimination of brief, steady-state consonant noise cues in Condition B might therefore lead to an REA. The latter alternative is suggested by findings of an adult REA for processing brief acoustic properties other than frequency or formant transitions, both in speech (REA for stop consonant noise burst identification, without formant transitions: Heymeyer & Sharf, 1974) and in nonspeech signals (REA for "plucked" vs. "bowed" sounds: Cutting, Note 9), for which adults also show categorical perception. Furthermore, newborns and one-month-old infants show left temporal lobe specialization in auditory evoked responses to auditory clicks (Davis & Wada, 1977; Wada, 1977).

Procedure: Methodological Considerations

As stated earlier, the cardiac OR (heart rate deceleration) was used as the dependent measure in a dichotic habituation/dishabituation test of three-to-four-month-old infants. It is a sensitive measure of infant response to stimulation, and has been used extensively in studies of infant attention, cognitive processing, and responsivity to stimuli (e.g., Lewis, 1974; Woodcock, 1971). In particular, it has been widely used in studies of infant speech perception (e.g., Miller & Morse, 1976; Moffitt, 1971; Morse, 1974; Miller, Morse & Dorman, Note 13) and nonspeech auditory processing (e.g., Kinney & Kagan, 1976; Lewis & Spaulding, 1967).

Although many infant speech perception studies have used high amplitude sucking rate as the dependent measure, that measure was decided against in the present study for several reasons. Operant conditioning of the sucking response is more time-consuming than habituation of the cardiac OR. Test sessions are thus longer, which means that infant state changes during testing are more likely to occur, possibly confounding the results and elevating the attrition rate of the subjects. Also, since test sessions are long for tests using the sucking rate measure, it is not practical to use a within-subjects design, which has obvious advantages in a dichotic study, and which could be used in the shorter sessions needed for tests using habituation of the cardiac response. Furthermore, interpreting a lack of recovery of the sucking rate response to a novel stimulus, after habituation of the response to the habituation stimulus, is ambiguous. On the one hand, a lack of recovery may indicate that the infant failed to discriminate the change, but on the other hand it may only indicate that the infant did not find the change reinforcing enough to increase his sucking rate (Butterfield & Cairns, 1974; Cutting & Eimas, 1975; Eilers & Minifie, 1973; Trehub, 1973). A similar logical problem arises when there is no evidence of dishabituation to a stimulus change following cardiac OR habituation. However, since the attentional or arousal-related recognition of change presumably associated with the dishabituation of a psychophysiological response is at a lower processing level than the operant behavioral response of increased sucking rate, it was decided that an attentional/arousal measure would be more sensitive to stimulus discriminations (i.e., would more frequently show dishabituation or recovery) than an operant measure such as sucking rate would.

A psychophysiological measure thus seemed more sensitive than the operant measure for the present study. A measure of electrocortical asymmetry was rejected for this study for several reasons, although AER asymmetries have been found in both infant and adult electrocortical responses to auditory stimuli. Age differences in AER asymmetry are confounded by large general changes in electrocortical activity during early infancy (Ellingson & Rose, 1970; Vaughan, 1975), and there is a lack of consensus about the cognitive or perceptual interpretation for electrocortical responses and the neural mechanisms producing the response. Theory and interpretation of cardiac responses in early infancy are more clearly delineated and agreed upon in the field of psychophysiology. Moreover, the nature of the AER measurement in infants does not allow a direct assessment of hemispheric asymmetries in discrimination among stimuli. It merely indicates a hemispheric asymmetry in the whole-brain neural response to individual stimuli. The present research measured cerebral asymmetries in discrimination among, and short-term auditory memory for, the phonemes in nonsense CV syllables.

In past studies of infant speech perception that have used a measure of cardiac responses, stimulus presentation has typically involved a rapid repetition of the syllable(s) being tested (e.g., a 1 second ISI has often been used). Stimulus presentation in the present study deviated from this pattern in that the ISI was variable and much longer in duration (variable 18 second ISI, range = 15 - 21 seconds), so that the cardiac response could be assessed individually for each single stimulus presentation, which cannot be done when the stimulus is rapidly repeated as in the typical infant speech perception study (in the latter type of study, a general change in heart rate is instead assessed over all stimulus repetitions). The stimulus presentation procedure used in the dissertation research is more faithful to the Soviet model of OR extinction and recovery (referred to in most U.S. studies of infant ORs as "habituation" and "dishabituation") as a measure of learning and stimulus discrimination (e.g., Sokolov, 1963, 1969). The duration of the ISIs allowed an assessment of cerebral asymmetries in infants' short-term auditory memory, and of their ability to discriminate a representation of the habituated dichotic auditory stimulus held in short-term auditory memory from a novel stimulus to either ear. The variable ISI was chosen rather than a fixed ISI in order to avoid confounding temporal conditioning of the cardiac response to a time-locked stimulus occurrence, with the cardiac response to the particular characteristics of the auditory stimulus (see Fitzgerald & Brackbill, 1976). Previous research has indicated that with ISIs of this duration, habituation of the cardiac OR typically occurs within eight to nine trials (Glanville, Best & Levenson, 1977; Best & Glanville, Notes 6 & 7; Glanville, Note 15; Glanville, Best & Hoffman, Note 8); therefore this study used nine dichotic habituation trials in each test.

Two groups of college students were also tested with the same experimental procedure, one group for Condition A (subsequently referred to as the Transitions Condition), and one for Condition B (Transitionless Condition). These adults were included to provide an appropriate basis of comparison for the infant findings, since there have been no previously reported studies of dichotic cardiac habituation/dishabituation tests of adults. Task demands are known to affect the degree and even the direction of adult cerebral asymmetries on various measures (e.g., Bartholomeus, 1974; Haggard & Parkinson, 1971; McKee, Humphrey & McAdam, 1973; Spellacy & Blumstein, 1970; Wood, Goff & Day, 1971). The task for the adults was made as similar as possible to that for the infants, for the reason just given. The adults were not asked to identify the phonemes in the syllables, nor were they told the stimuli were dichotic. They were told only that they would hear nonsense speech sounds presented in several series (actually, four series) at irregular intervals, and should listen for a change in the sounds during each series. It was expected that if the acoustic properties of the speech stimuli are important in producing adult cerebral asymmetries, previous findings should be replicated of an REA for consonants in syllables containing formant transitions, and no ear advantages for vowels in either condition. Since previous reports from studies of consonant identification in transitionless syllables have been inconsistent regarding whether adults show an REA for consonant noise cues alone (e.g., Darwin, 1971; vs. Heymeyer & Sharf, 1974), it was not clear whether the adults would show a consonant REA for Condition B (Transitionless Condition). However, if adults must engage in phonetic processing of encoded consonants in order to show an REA for consonant discrimination, the results from the present dichotic study might deviate from previous studies since the adults were not asked to use phonetic processing, and might fail to support a consonant REA in either test condition.

Summary: General Procedure and Predictions

A dichotic habituation/dishabituation procedure was used to determine cerebral asymmetries for speech perception in two groups of three-to-four-month-old infants and two groups of college students. The cardiac OR, measured as heart rate deceleration, was the dependent measure. In the procedure used, each test consisted of nine repetitions of a dichotic pair of syllables designated as the habituation stimulus, with a variable 18 second ISI, during which the cardiac OR was habituated to the stimulus pair. Then a test trial (trial 10) was presented, in which a novel stimulus was presented to one ear while the other ear again received its habituation stimulus. The subjects in each of the two test conditions each received four dichotic tests: one left- and one right-ear test each for tests of consonant discrimination and for tests of vowel discrimination. The same sets of nonsense CVs were used in both conditions, with the restriction that the subjects in Condition A (Transitions Condition) heard syllables containing formant transitions, while the subjects in Condition B (Transitionless Condition) heard transitionless syllables. Recovery of the cardiac OR on each test trial was assessed, relative to the cardiac response on the last habituation trial of that test, and ear differences were determined for the two stimulus types (consonant versus vowel) and for the two conditions.

The predictions were:

1. if encodedness is important for infant left hemisphere processing as it is proposed to be for adults, the infants in Condition A (Transitions Condition) should show an REA for consonant discrimination, and no ear differences for vowel discrimination;
2. if formant transitions are important acoustic cues for infant left hemisphere processing, as some research suggests they are for adults, the infants in Condition B (Transitionless Condition) should show no ear differences for consonant or vowel discrimination;
3. if brief, transient cues are important for infant left hemisphere processing, the infants in Condition B may show an REA for consonant discrimination;
4. if steady-state, multi-frequency acoustic cues are important for infant right hemisphere processing, the infants in Condition B may show an LEA for vowel discrimination;
5. if phonetic decoding is important for adult left hemisphere processing, the adults in both conditions should show no ear asymmetries for either vowel or consonant discrimination;
6. if formant transitions are important acoustic cues for adult left hemisphere processing, the adults in Condition A should show an REA for consonant discrimination, but the adults in

Condition B should show no consonant ear asymmetry, and neither group should show ear asymmetries for vowel discrimination;

7. if brief, transient acoustic cues are important for adult left hemisphere processing, the adults in Condition B as well as in Condition A should show a consonant REA.

METHOD

Infant Subjects

A total of eighty-three infants from thirteen to seventeen weeks of age participated in the experiment. Of these, thirty-two infants who completed the test session (sixteen males and sixteen females) comprised the final data set. Condition A (Transitions Condition) had eight male and eight female infant participants; Condition B (Transitionless Condition) was filled by the other eight male and eight female infants (see Table 1 for exact age characteristics of the infants who completed the experiment, and those who did not). None of the infants included in the final data set had a history of prenatal or perinatal complications, was taking medication at the time of testing, or had any suspected personal or familial hearing impairments, other than familial loss due to aging or trauma. With the exception of a few cases in which one of the infant's parents had stuttered as a child, there were no instances of serious familial language disturbance.[1]

The other fifty-one infants who participated either failed to complete the test session, or were removed from the data pool for various reasons. The attrition rate was thus approximately sixty percent, which is in line with reported attrition rates in other studies of infants around this age, and was virtually identical for

Table 1. Age characteristics of infant participants.

		Age(days):		
	N	Mean	S.D.	Range
Infants who completed experiment:				
Condition A: (Transitions Condition)	8 males	110.0	6.19	96-115
	8 females	107.25	6.88	93-117
Condition B: (Transitionless Condition)	8 males	112.5	4.28	109-118
	8 females	110.88	4.05	103-116
Infants who did not complete experiment:	26 males	97.73	10.07	84-117
	25 females	101.6	10.61	89-120

males (61.90%) and females (60.98%). The most frequent cause for subject loss was crying, and the second most frequent cause was sleeping. Infants were removed from the final data set if they cried for more than one minute continuously during testing, or if they fell asleep during testing for more than two consecutive minutes, since those state changes alter cardiac responsivity and base rate (e.g., Lewis, Bartels & Goldberg, 1967). If necessary, attempts were made to quiet or awaken the infant during the breaks between test sequences. Several other infants were excluded because of pregnancy or birth complications, or parental or sibling interference during one of the test sequences, or experimental error/equipment failure.

The infant subjects were obtained via mail recruitment. County birth records and local newspaper birth announcements were used to compile lists of parents of young infants in the greater Lansing area (within 15-20 miles of the laboratory). These parents were mailed one of two similar letters briefly describing the study (see Appendix A), which requested them to consider bringing their infant in to the Infant Learning Unit of the Developmental Psychobiology Laboratory at Michigan State University at around three-and-a-half months of age (although infants were included in testing at any age between three and four months).[2]

Procedure[3]

All infants in each of the two test conditions (A & B) took part in four dichotic habituation/dishabituation tests during which their heart rate was monitored for cardiac orienting (OR), or heart rate deceleration, to the stimulus presentations. The first nine trials of each test were habituation trials. On each habituation trial, the dichotic syllable pair designated as the habituation pair was presented once over stereophonic headphones, such that one ear received one syllable of the pair while the other ear received the other syllable of the pair. The tenth trial of each test was a test trial, in which one ear received a novel test syllable from the same discrimination set as the habituation pair (a set testing for consonant discrimination or vowel discrimination), while the other ear again received its habituation syllable. This procedure allowed assessment of one ear's (and the contralateral cerebral hemisphere) recognition of the syllable change. Intertrial intervals (ITIs) within each test varied randomly from 15 to 21 seconds (M = 18 sec), to allow enough time between trials for the heart rate to return to the prestimulus baseline level (e.g., Graham & Jackson, 1970), and to avoid the possibility of confounding by temporal conditioning (e.g., Fitzgerald & Brackbill, 1976). There was an approximately one-minute break between test sequences to reverse headphone channels through a switchbox on the tape recorder, and to align the stimulus tape for the next test sequence.

Each infant received two dichotic discrimination tests for each of the following two types of phoneme: (1) vowels; and (2) consonants. The stimulus sets used for each of the four tests, and the differences between the syllables used in the two test conditions, are described in the next section (see Stimuli). For each of the two tests within each phoneme type, the novel syllable was presented to the left ear on trial 10; for the other test within each phoneme type the novel syllable was presented to the right ear on trial 10. Figure 1 is a schematic

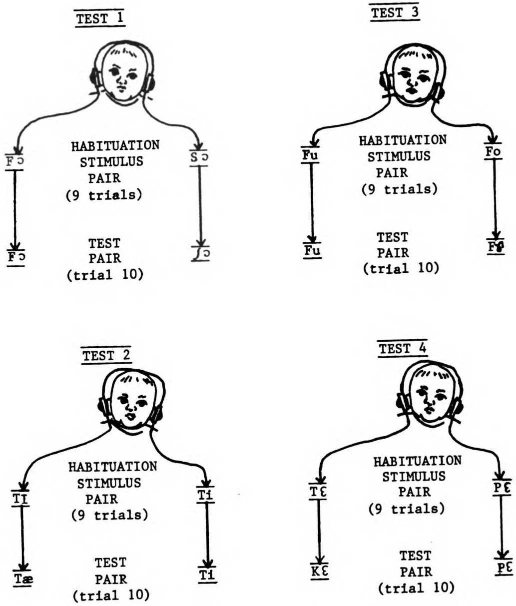


Figure 1. Schematic diagram of the test procedure, showing stimulus and test sequence for an example subject. For this subject, the sequence is: Test 1 - Consonant/Left Ear Test; Test 2 - Vowel/Right Ear Test; Test 3 - Vowel/Left Ear Test; Test 4 - Consonant/Right Ear Test. See text for further procedural details.

diagram of the test procedure for one infant. Order of tests for the two phoneme categories were counterbalanced between subjects within each test condition, whereas presentation order for ear receiving the novel test syllable on trial 10 within each phoneme type was counterbalanced within subjects. Test orders for phoneme type and ear tested were pre-determined with the constraint that left-ear and right-ear tests be alternated, for a total of sixteen test orders within each condition. These test orders for each condition were randomized and listed prior to the experiment, for assignment of subjects to condition A or B and to the various test orders within each condition. According to the sequence listed, infants were assigned to a condition and test order as they arrived, such that a given condition + test order combination had to be successfully completed by one infant before the next condition + test order combination on the list could be assigned.

Testing was conducted in a soundproof chamber in the Infant Learning Unit of the Developmental Psychobiology Laboratory at Michigan State University. The chamber was approximately 1 1/2 m. x 1 1/2 m., and had a small one-way mirror about 1 m. up from the floor on one side. There were electrical connections from a wall coupler in the chamber to a Grass model 7 polygraph used for the psychophysiological recording. The polygraph was in the room adjacent to the Infant Learning Unit, and was operated by the experimenter during testing. The infant sat in the parent's lap during the session, or in some cases stood up in the parent's lap facing over the shoulder, so that the infant's face was visible through the one-way mirror to an assistant seated outside the chamber. The other parent, if present, usually sat in the chamber, behind and to the side of the parent holding the infant. An assistant located outside the chamber ran the tape recorder which controlled stimulus presentations.

In addition, the assistant continually monitored through the one-way mirror the infant's state according to the six-level biobehavioral state scale (see Table 2) developed by Brackbill and Fitzgerald (1969). The state information was recorded on six channels of an Esterline-Angus chart recorder. Stimulus occurrences were automatically recorded on a seventh channel of the recorder, through a switch connection from the tape recorder to a pulse former, so that state could be assessed relative to stimulus occurrences. If the infant was a pacifier user, and fussed during the session, pacifier use was allowed. Bottles also were allowed. Although some researchers have claimed that sucking suppresses directional heart rate response in newborns and probably in older infants (e.g., Nelson, Clifton, Dowd, Appleton & Little, Note 16; Nelson, Clifton, Dowd & Field, Note 17), a recent study has shown that by at least six weeks of age infants show directional heart rate responses to auditory nonspeech and speech stimuli independent of concurrent changes in sucking rate (Leavitt, Brown, Morse & Graham, 1976). Mean biobehavioral state during the test sessions was 4.29, which is between quiet awake and active awake states on the state scale, and was virtually identical for prestimulus ($\underline{M}$ = 4.22) and post-stimulus periods ($\underline{M}$ = 4.29).

When the infant and parent(s) arrived, the parents were greeted and asked to read a written explanation of the experimental procedure (see Appendix B), which included a description of the preparations made for recording the electrocardiogram (ECG). While the parents were reading, the experimenter and assistants acquainted the infant with the

Table 2. Scale used for rating infant biobehavioral state during the test session (adapted from Brackbill & Fitzgerald, 1969).

1	Quiet Sleep	General muscular relaxation, entire body Brief startles, apparently spontaneous Eyes usually closed Regular respiration
2	Active Sleep	Relatively frequent diffuse movements, often extremities but may be whole body often small movements of face muscles (suck, grimace, etc.) Occasional conjugate eye movements (REMs) Eyes closed Irregular respiration
3	Drowsy	Motor behavior sort of jerky, with gradual relaxation interspersed with sudden jerks to waking state Eyelids flutter Eyes appear glassy when visible Respiration more regular than irregular
4	Quiet Awake	Little movement of whole body, some small movements of face and extremities Eyes open, appear bright and shiny Appears peaceful, vocalizations not of "fussy" variety Relatively regular respiration
5	Active Awake	Considerable whole-body activity Respiration often irregular May be much vocalization, which may include "fussing"
6	Crying	Same criteris as for Active Awake, except infant is also crying (with or without tears) Onset of the Crying state is often marked, sustained protest movements and vocalizations

laboratory and with themselves. Following this initial introductory period of about five minutes, the parents were asked to sign the informed consent form, and to fill out information feedback forms and background information sheets (see Appendix C).

While the parent(s) filled out the forms, the experimenter prepared for ECG recording. The recording sites on the infant's torso were first gently cleaned with sterile 70 percent ethanol wipes, and then Beckman Ag/AgCl biopotential electrodes were taped in position with sterile micropore tape, using Beckman Offner Paste as the electrolytic medium. The two recording electrodes were taped on the infant's chest, 2.5 cm. above each nipple, and a ground electrode was taped 2.5 cm. above the navel. The electrodes were then connected via a coupler cable in the experimental chamber to the polygraph. The ECG was recorded on the polygraph through a Grass model 7P6 A ECG preamplifier, and at the same time was recorded on magnetic tape through an FM channel of a Vetter model A Recording System for later computer digitization of the interbeat intervals (heart period, or HP) and transformation of HP data to heart rate in beats-per-minute (BPM) for analysis. Stimulus occurrences were automatically recorded through the pulse former on the event channel of the polygraph and on a separate audio channel of the Vetter recorder.

When everything was ready for testing to begin, a second assistant inside the test chamber placed the headphones over the infant's ears in correct position. The stimuli were presented from a Revox half-track reel-to-reel tape recorder at 75 db (Scale A, Bruel & Kjöer Sound Level Meter Type 2203; a headphone coupler was devised and used for accuracy in these measurements--see Putnam, Graham & Sigafus, 1975), through light-weight Sennheiser HD-44 open-air headphones modified for infant head size. Testing proceeded from one test to the next, with only a short break between test sequences, unless the infant was fussy, or needed a bottle or a diaper change.

Stimuli

Four sets of computer-synthesized consonant + vowel syllables (CVs) were used in each test condition. Each set consisted of the two CV syllables in the dichotic habituation pair, and a third syllable which served as the novel test stimulus in the dichotic test pair. Within a set, syllables differed only with respect to the phoneme to be discriminated; that is, in the sets used for dichotic tests of consonant discrimination only the consonants differed among the CV syllables in the set (the vowel identity was held constant from syllable to syllable), and the converse was true of the sets used for dichotic tests of vowel discrimination. In each condition, there were two sets of syllables for dichotic consonant discrimination tests (one set each for testing each ear), and two sets of syllables for dichotic vowel discrimination tests. The four test sets for Condition A (Transitions Condition) were: (1) /pε/, /tε/, /kε/; (2) /fɔ/, /sɔ/, /ʃɔ/; (3) /ti/, /tI/, /tæ/; and (4) /fu/, /fo/, /fɝ/. All syllables were 300 msec. in total duration, and contained formants F1, F2 and F3 only (no significant acoustic energy was present for F4, F5 or F6). The fundamental frequency, or perceived pitch, represented an average male voice, and the pitch contour was identical for all syllables. The fundamental frequency began at 120 Hz for each syllable and rose linearly to 130 Hz by 100 msec., where it remained up to the last 50 msec. of the syllable, during which it fell linearly to a final 100 Hz. The Condition A syllables all contained formant transitions in the aspiration and initial segments of the vowel formants, between the consonantal noise (stop bursts or frication noise) and the steady-state portion of the vowel formants. The same four sets of syllables were also used in Condition B (Transitionless Condition), differing from those used in Condition A only in that the formant transitions in the aspiration and vowel onset between the consonantal noise and the steady-state vowel formants, were "straightened out" to equal the steady-state frequency values of the vowel formants. The syllables used were chosen because their consonants could be accurately identified even in syllables synthesized without formant transitions, as for Condition B (e.g., Dorman, Studdert-Kennedy & Raphael, 1976). All eight sets of syllables were synthesized at Haskins Laboratories on their computer-controlled (DDP-224) serial resonance synthesizer (FONEMA, model OVE-III), then digitized in PCM (the computer's _P_ulse _C_ode _M_odulation software-controlled A/D system for analog-to-digital conversion of the acoustic waveform), and output from the computer to audio tape.

To assess the identifiability of the test stimuli described above, two groups of adult subjects (twenty at Michigan State University and eight at Haskins Laboratories in New Haven, Connecticut) completed standard forced-choice identification tests on randomized sequences of several tokens of each of the complete and transitionless CV syllables finally used in the four basic sets of three syllables for the dichotic discrimination study. Several different tokens of each syllable were computer-synthesized for inclusion in the identification study, varying slightly in certain acoustic parameters critical for identification of the consonant in the syllable. Based on the identification tests, the most highly identifiable token of each syllable was chosen for use in the dichotic study. The syllables chosen all received ninety percent or better correct identification scores, with the exception of the best-identified token of the transitionless /kɛ/, which was correctly identified eighty percent of the time (see Table 3). Informal testing of other computer-synthesized tokens of transitionless /kɛ/ indicated that it is very unlikely to obtain better than eighty percent correct identification for that syllable. The other two members of that test set, transitionless /pɛ/ and /tɛ/, were each one-hundred percent correctly identified. The conditional probability of failure to discriminate /kɛ/ from /pɛ/ or /tɛ/ is thus .2. It was therefore decided that the members of the transitionless test set as a whole were discriminated and identified well enough by adults that they were appropriate for use in the dichotic study, even though the identification performance for /kɛ/ is slightly lower than the level usually considered acceptable in identification tests (87% is the standard cut-off).

Figures 2 and 3 show schematic spectrograms of the stimuli used in the dichotic study, plotted on the graphics terminal controlled by the Haskins DDP-224 computer following its A/D spectrographic analysis of the syllables. The spectrograms illustrate an analysis of the auditory frequencies present in the signals, plotted as a function of time in milliseconds. The straight bar-like portions of the spectrograms in the final parts of the syllables correspond to the

Table 3. Percent correct identifications of syllables chosen for use in the infant study.

		Condition A (Transitions Condition):	Condition B (Transitionless Condition):
Set 1	Pɛ	100%	100%
	Tɛ	100%	100%
	Kɛ	90%	80%
Set 2	Fɔ	93%	94%
	Sɔ	100%	100%
	ʃɔ	99%	99%
Set 3	Ti	100%	100%
	TI	95%	93%
	Tæ	100%	100%
Set 4	Fu	98%	98%
	Fo	96%	91%
	Fɝ	99%	100%

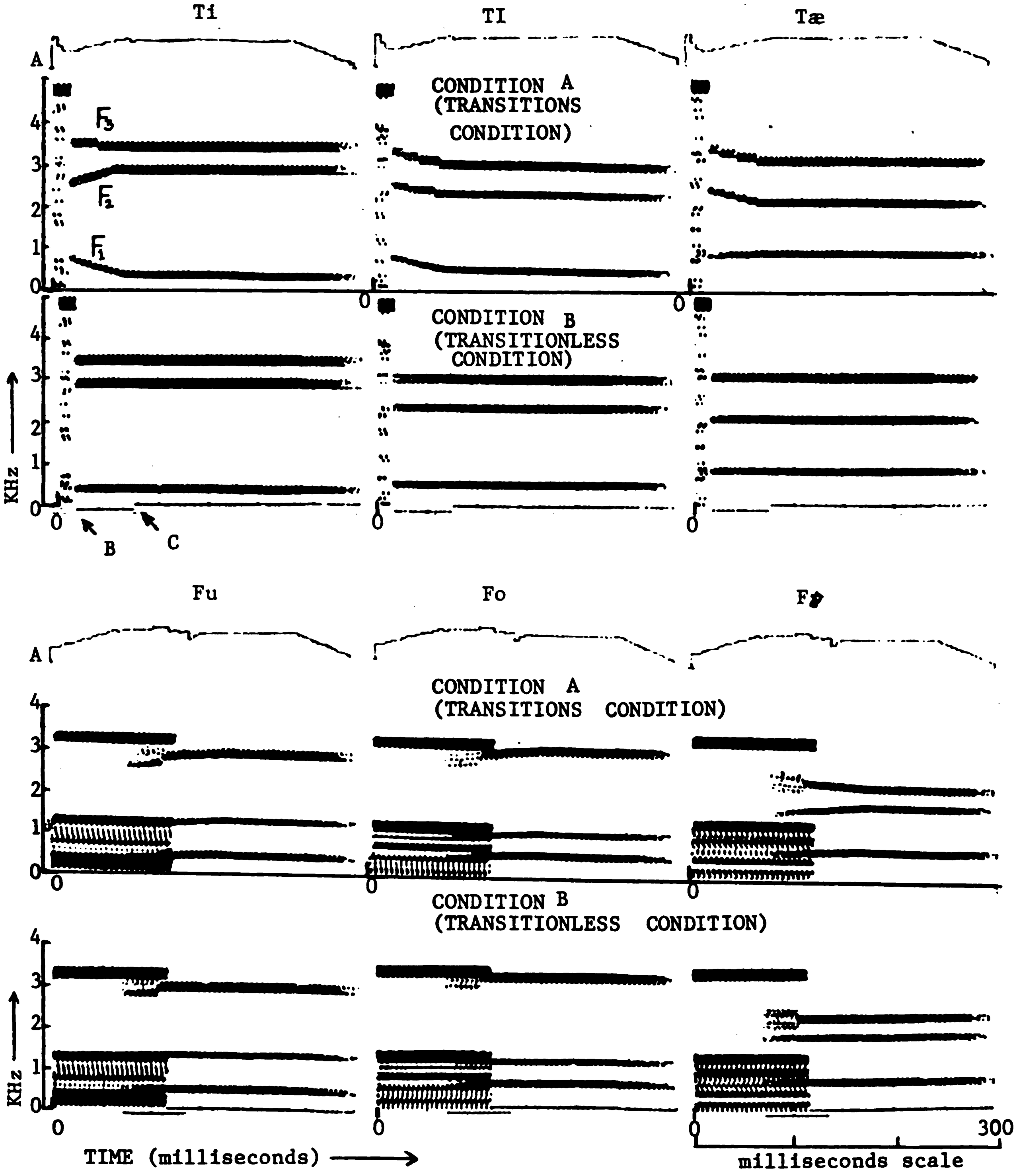


Figure 2. Computer-generated schematic spectrograms of the stimuli used for vowel discrimination tests. Amplitude envelopes for each syllable are above the spectrograms (A), and the line below the spectrograms represents the onset of aspiration (B) and the onset of voicing (C).

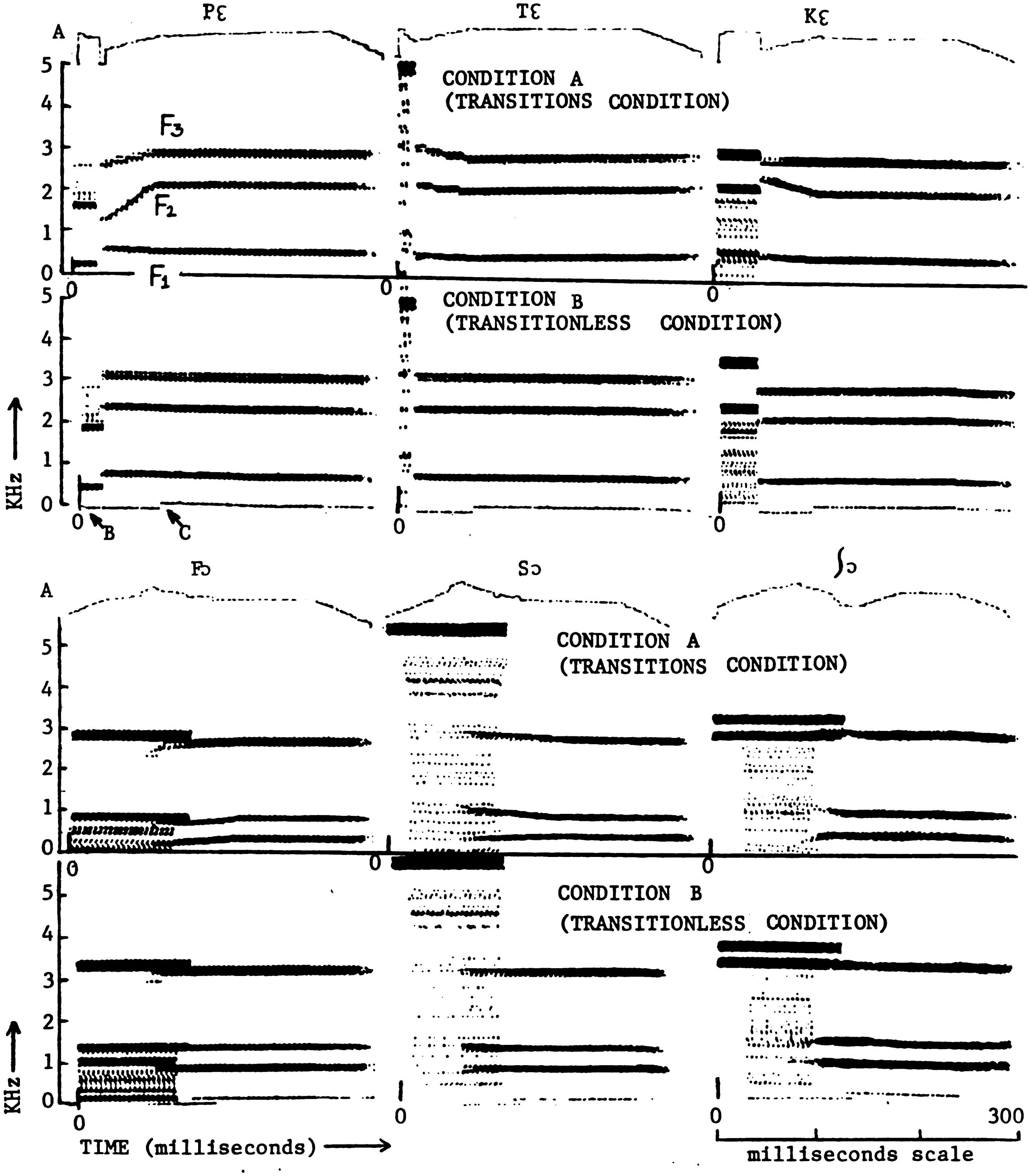


Figure 3. Computer-generated schematic spectrograms of the stimuli used for consonant discriminations.

vowel formants, and represent the periodic acoustic energy produced by glottal (laryngeal) vibrations during voiced speech sounds. The briefer, "dotted" or "striated" initial portions of the syllables that precede the vowel formants represent the consonantal noise that occurs with the passage of air through constricted areas of the vocal tract during consonant articulation, and contain high-intensity frequency-limited aperiodic noise. Between the consonant noise cues and the onset of the voiced vowels are the aspirated parts of the syllables, during which low-intensity noise occurs with the passage of air through a relatively nonconstricted vocal tract. The transitional elements for the Condition A syllables occur largely during the aspirated portions of the syllables, as can be seen in the Condition A spectrograms of Figures 2 and 3. The transitions in the aspirated parts of the syllables are more easily seen in the schematic spectrograms than in actual spectrogram analyses of the syllables by a Sonograph (see Appendix D, Figures D1 and D2).

The syllables chosen for the dichotic study were output from the Haskins Laboratories computer in their proper dichotic test sequences. Each of the eight test sequences consisted of nine presentations of the dichotic habituation stimulus pair (e.g., /pɛ/ in channel 1 + /tɛ/ in channel 2 of the stimulus tape), followed by a tenth dichotic test trial in which one ear received the novel test stimulus while the other ear again received its habituation stimulus (e.g., /pɛ/ in channel 1 + /kɛ/ in channel 2). The test stimulus for trial 10 was always presented on channel 2 of the stimulus tape. For set 1 the habituation pair was /pɛ/ + /tɛ/, and the test pair /pɛ/ +

/kɛ/; for set 2 the habituation pair was /fɔ/ + /sɔ/, and the test pair /fɔ/ + /ʃɔ/; for set 3 the habituation pair was /ti/ + /tI/, and the test pair /ti/ + /tæ/; for set 4 the habituation pair was /fu/ + /fo/, and the test pair /fu/ + /fʊ/ (refer again to Figure 1 for illustration).

Adult Subjects

A group of adult subjects was also tested according to the same procedure, to provide a more appropriate comparison for the infant findings than would be provided by other types of tests of adult dichotic abilities, as mentioned in the Introduction. The thirty-two adults (eight males and eight females in each of the two experimental conditions) were recruited from introductory social psychology and introductory developmental psychology classes at Michigan State University. Approximately two-thirds of these subjects received extra course credit for their participation; the rest were volunteers. None of the subjects themselves had known hearing impairments or language disturbances, nor were there any familial hearing abnormalities other than those related to old age or trauma, nor any familial language disturbances other than one case of stuttering in one sibling. All subjects had to be right-handed according to their score on a 13-item hand preference questionnaire on common unimanual activities[4] (see Background Information Sheet, Appendix E). Mean age of the female subjects was 21.38 years (S.D. = 2.66; range = 18-28); mean age for males was 22.75 years (S.D. = 3.88; range = 19-34). Two additional males and eight females also participated, but their data were removed from the final data set because of equipment failure/poor psychophysiological recordings

(5 subjects), self-reported nonalertness (2 Ss), strong left-handed tendency (1 S), and hearing impairments (1 S).

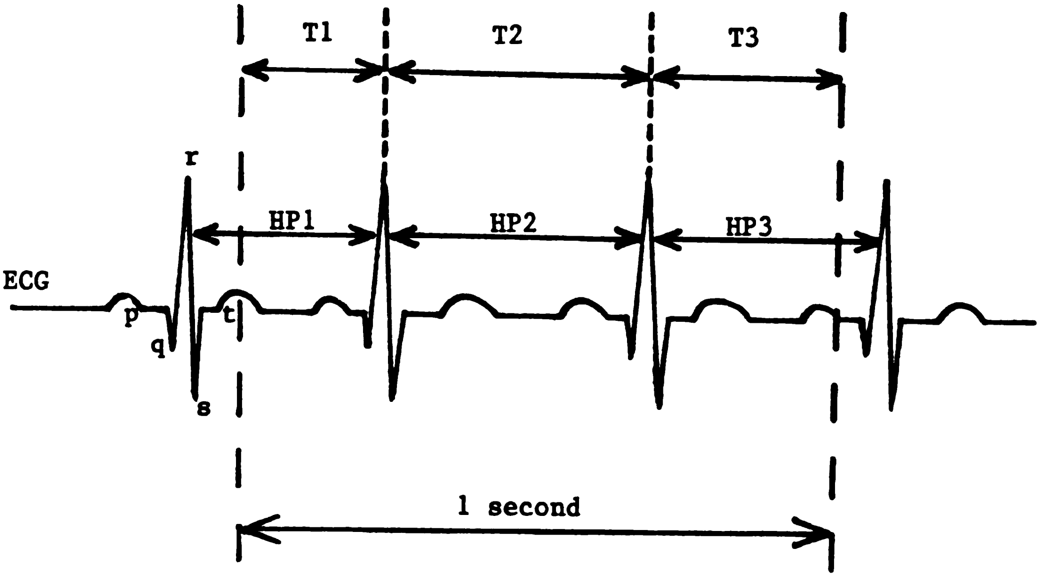
Procedure

Adult subjects were tested while seated in a comfortable chair, which was in the experimental chamber described earlier. Once they arrived at the laboratory, they were asked to read a written description of the procedure and test instructions (see Appendix F) which requested them to listen carefully to the speech sounds they would be hearing, so that they could detect whether a change in the sounds occurred during any of the four test sequences each subject received. The instructions were designed to make the test situation for the adults as similar as possible to that for the infants. Therefore, the adults were specifically not asked to identify the phonetic quality of the syllables or of the stimulus change. They were simply asked to listen for some change, which may or may not have occurred during a given test sequence, and to report whether they heard a change for each sequence. Instructions to listen for a change were included because preliminary research in another lab suggested that adult cardiac responses in a dichotic speech test dishabituate significantly only if subjects are instructed to listen for a stimulus change (Cowan & Morse, Note 18). After the subjects understood the instructions, they were asked to fill out the official permission form and the background information sheets (see Appendix E). Recording sites were prepared as for the infants; however, the recording electrodes were taped on the inside of the subject's forearm, 2.5 cm. above the wrist, and the ground electrode was taped on the inside of the left ankle about 2.5 cm. above the ankle bone.

The remainder of the procedure was the same as that described for the infant sample, including counterbalancing of test sequences and assignment of subjects to test orders and conditions, with the exception that there was no additional assistant in the chamber with the subject, and state was not recorded.

Scoring

The heart rate data were scored in the same manner for the thirty-two infants and thirty-two adults who had satisfactorily completed the four dichotic tests of the experimental condition (A or B) to which they had been assigned. The raw ECG data were digitized and averaged on a PDP12/LINC12 computer at the Waisman Center of the University of Wisconsin at Madison.[5] The ECG data tapes were played into the graphics terminal of the computer so that each cardiac R-wave (see Figure 4), typically used as a reference point in ECG scoring to demarcate a single heart beat, triggered the computer's internal clock. The computer program determined the duration in milliseconds of each R-R interval, or heart period, for the two seconds immediately preceding stimulus onset and the eleven seconds following stimulus offset on each of the ten trials of the four dichotic discrimination tests for each subject. From these heart period data the weighted average heart rates were computed for all stimulus presentations, during the one second immediately preceding stimulus onset and during each of the ten seconds following stimulus offset (the additional prestimulus and poststimulus second were needed to avoid loss of partial heart period data at the beginning and end of each scoring interval). Ten poststimulus seconds was chosen as the measurement interval because studies of the



T_i = interval (in msec) of the given second during which heart beat HP_i occurred

HP_i = heart period in msec for beat i (R - R interval, or complete cardiac cycle)

$$\text{weighted average heart rate/sec (in BPM)} = 60\left[\frac{1}{\sum_i\left(\frac{T_i}{HP_i}\right)}\right]$$

Figure 4. Simplified schematic diagram of the computer algorithm for calculating weighted average heart rate in beats-per-minute (BPM) from the raw electrocardiogram (ECG) during one second in real time (components of the cardiac cycle are designated for the first beat on the left-hand side of the figure).

second-by-second course of cardiac decelerations (ORs) in young infants (1 1/2 - 4 months) indicate that peak deceleration is typically achieved around the fifth poststimulus second, after which heart rate usually returns to the prestimulus level by about the tenth poststimulus second (Graham & Jackson, 1970; Berg, Berg & Graham, Note 19; Hatton, Note 20).

The weighted average heart rate for each second was determined as follows: the total duration in milliseconds of each beat that even partially fell within a given second was used to divide the proportion of the second (msec) which had been filled by that beat; then the reciprocal of the sum of those quotients for the given second were multiplied by 60 to yield the average heart rate in beats-per-minute (BPM) for that second (see Figure 6 again, for a schematic diagram and simplified computational formula). The weighted average, rather than a simple equal-weight average, was computed because it is a truer reflection of the actual average heart rate during a specified real-time unit (Graham, Note 21). Equal-weight averaging often produces spuriously high, and sometimes low, estimates of the true average heart rate for a given period of real time (Thorne, Engel & Holmblad, 1976). Heart rate rather than heart period was scored since statistical comparisons were based on real-time units (secs) and not on cardiac time units (beat intervals--see Graham, Note 22, for a discussion of differences in the use of heart rate and heart period for statistical comparisons based on real time versus cardiac cycle time, respectively).

The weighted average heart rate data were used to determine the change from the prestimulus heart rate for each of the ten poststimulus seconds on the ten trials in each of the four dichotic habituation/dishabituation tests for all subjects. These heart rate difference scores were determined by subtracting the heart rate in BPM for the prestimulus second on a given trial from the heart rate in BPM during each of the ten poststimulus seconds on that trial.

RESULTS

Summary of Analyses

Analyses of variance on the heart rate difference scores were performed separately for each of the following groups of subjects: (1) Condition A infants; (2) Condition B infants; (3) Condition A adults; and (4) Condition B adults. For each of these four groups, five overall equal-n repeated measures analyses of variance (ANOVAs) were performed on various portions of the heart rate difference score summary data. The repeated measures (within-subjects) factors in these analyses were Phoneme (vowel vs. consonant discrimination test), Ear (left vs. right ear receiving the novel stimulus on trial 10 of a given test block), Trials (within test blocks), and Seconds (heart rate difference scores on each of the ten poststimulus seconds for trials within test blocks). The between-subjects factor was Gender (male vs. female), and the Individual factor (subjects) was nested in Gender but crossed with all other factors.

For each of the four groups of subjects, the occurrence of habituation was assessed during the habituation trials (trials 1 through 9 of all four tests) through a Gender (2) x Seconds (10) x Trials (1 through 9) x Phoneme (2) x Ear (2) ANOVA. The amount of change in cardiac responses from the first to the last habituation trial was determined via a second habituation trial ANOVA for the factors named above, on trials 1 and 9 alone rather than all nine trials, thus making the Trials factor two-level.

To assess the response on the last habituation trial alone, and any differences in heart rate on that trial for the Gender, Phoneme, and Ear factors, a Seconds x Gender x Phoneme x Ear ANOVA was performed on the trial 9 data. The trial 9 analysis was run so that discrimination of the stimulus changes on trial 10 of all tests could be compared appropriately to the responses on the last habituation trial, and thus trial 10 dishabituation relative to trial 9 could be assessed.

To find whether dishabituation occurred on trial 10, and whether there were any differences among the factors in the trial 10 dishabituation, a Seconds x Trials (2) x Gender x Phoneme x Ear ANOVA was performed for trials 9 and 10 of all tests. The differences in trial 10 cardiac dishabituation for the various factors were directly tested via a Seconds x Gender x Phoneme x Ear ANOVA for the trial 10 data on all tests. Significant interactions in the ANOVAs which are of theoretical interest were broken down by simple simple effects and simple main effects tests (Kirk, 1968; Winer, 1962), for statistical comparisons among the levels of the factors that contributed to the interactions.

Overall, these analyses indicated that the adults in both conditions, and a large subset of infants in both conditions, showed cardiac OR habituation during the habituation trials of all tests. The OR habituation suggests that these subjects had formed some perceptual or cognitive model for the stimulus characteristics of the dichotic habituation syllables. The pattern of cardiac OR dishabituations to the stimulus change on the test trial among adults indicated that they discriminated the vowel changes in both conditions, and did so equally well with both ears (cerebral hemispheres). However, the adults in neither condition discriminated the consonant changes in this dichotic habituation/dishabituation test. The adult failure to discriminate consonant changes involved both ears (hemispheres) equally in each condition.

Those infants in Condition A (Transitions Condition) who showed habituation provided moderate evidence for discrimination of both vowel and consonant changes, without any ear asymmetries in either case. Individual analyses suggested that for each of the four tests (Vowel/Left Ear, Vowel/Right Ear, Consonant/Left Ear, and Consonant/Right Ear), about half of the Condition A infants clearly discriminated the stimulus change on the test trial. The infants in Condition B (Transitionless Condition) who showed habituation provided evidence in their test trial dishabituations only for left ear vowel discrimination (right hemisphere advantage) and right ear consonant discrimination (left hemisphere advantage). The detailed results of these analyses for adults and infants are described next.

Adults

The adult subjects were included as an appropriate comparison group for the infant subjects, rather than being considered as part of a separate study. However, since there were some differences in the findings with the adults in this study relative to earlier reports of adult cerebral asymmetries for consonant and vowel processing of CV syllables with and without formant transitions, the adult data will be described first to provide an appropriate framework from which to consider the infant findings. The results for all analyses of adults in Condition A (Transitions Condition) are described first, since the syllables in that condition were acoustically more similar to "natural" speech than were the transitionless stimuli. Then the results for the adults in Condition B (Transitionless Condition) are reported. Following the sections describing the adult findings, the results from the infant data are reported. Significant results for all analyses with both age groups are listed in ANOVA tables in Appendix G.

Condition A (Transitions Condition)

Habituation trials analyses.--The adult subjects in Condition A (Transitions Condition) showed a small, brief, but reliable cardiac OR following dichotic stimulus presentations during the habituation trials in all tests, as indicated by a significant Seconds main effect, F (9, 126) = 4.18, $p < .0005$, illustrated in Figure 5. The figure illustrates the typical general form of the cardiac OR--an immediate poststimulus deceleration followed by an acceleration and then a general return to the prestimulus heart rate level. Trial-to-trial changes in the magnitude and form of the cardiac response during the nine habituation trials across all four dichotic consonant and vowel discrimination tests are shown in Figures 6 and 7 (response magnitude is represented as the mean pre- to poststimulus heart rate difference score summed over all ten poststimulus seconds on a given trial, as seen in Figure 6). The Trials main effect indicates that the trial-to-trial change in mean heart rate difference scores during the habituation trials was not quite significant. In addition, the Seconds x Trials interaction fell short of statistical significance, indicating an unreliable change in the form of the second-by-second poststimulus heart rate response

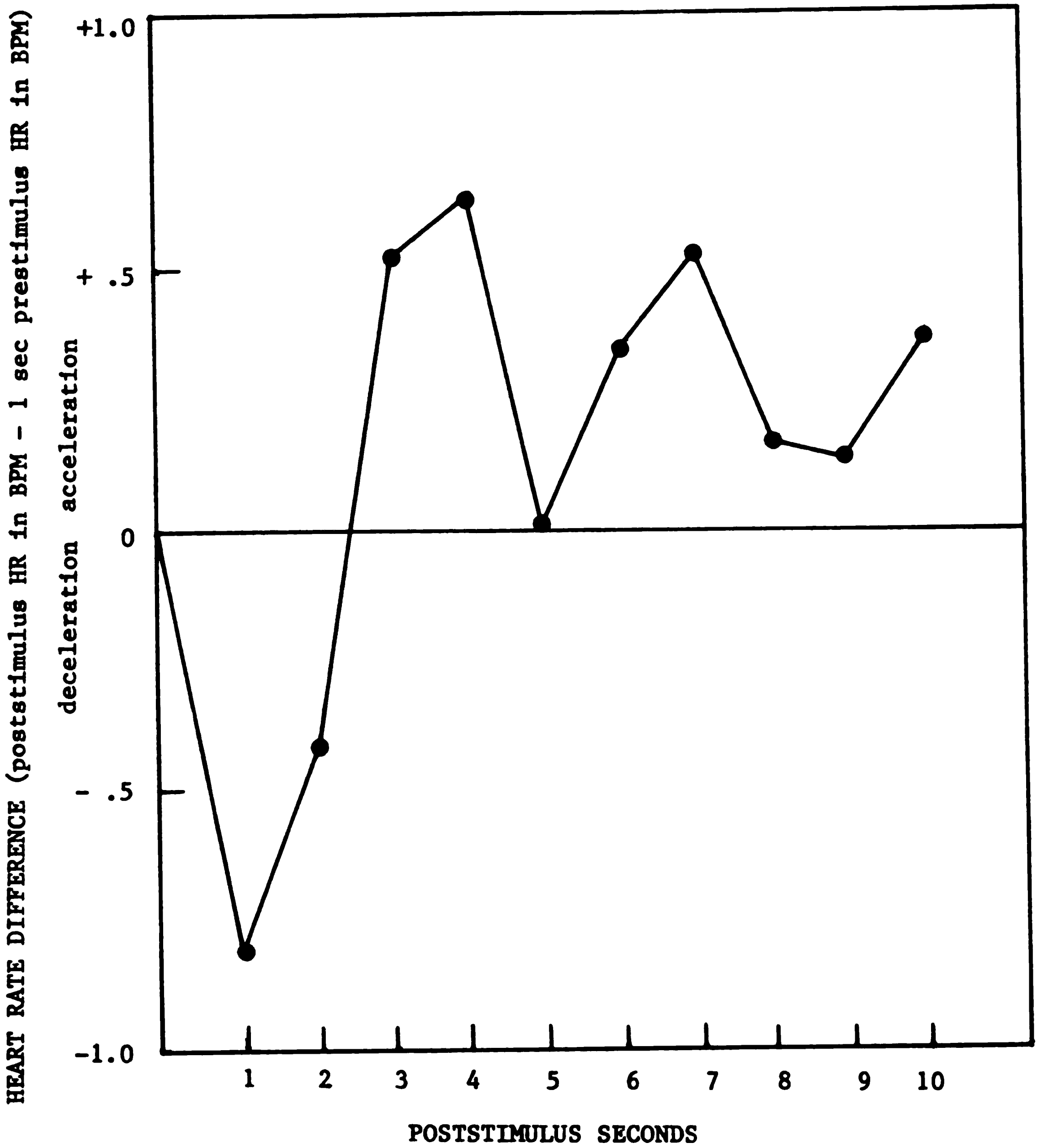


Figure 5. Second-by-second evoked poststimulus heart rate response, averaged over the habituation trials (1 through 9), for the adults in Condition A (Transitions Condition).

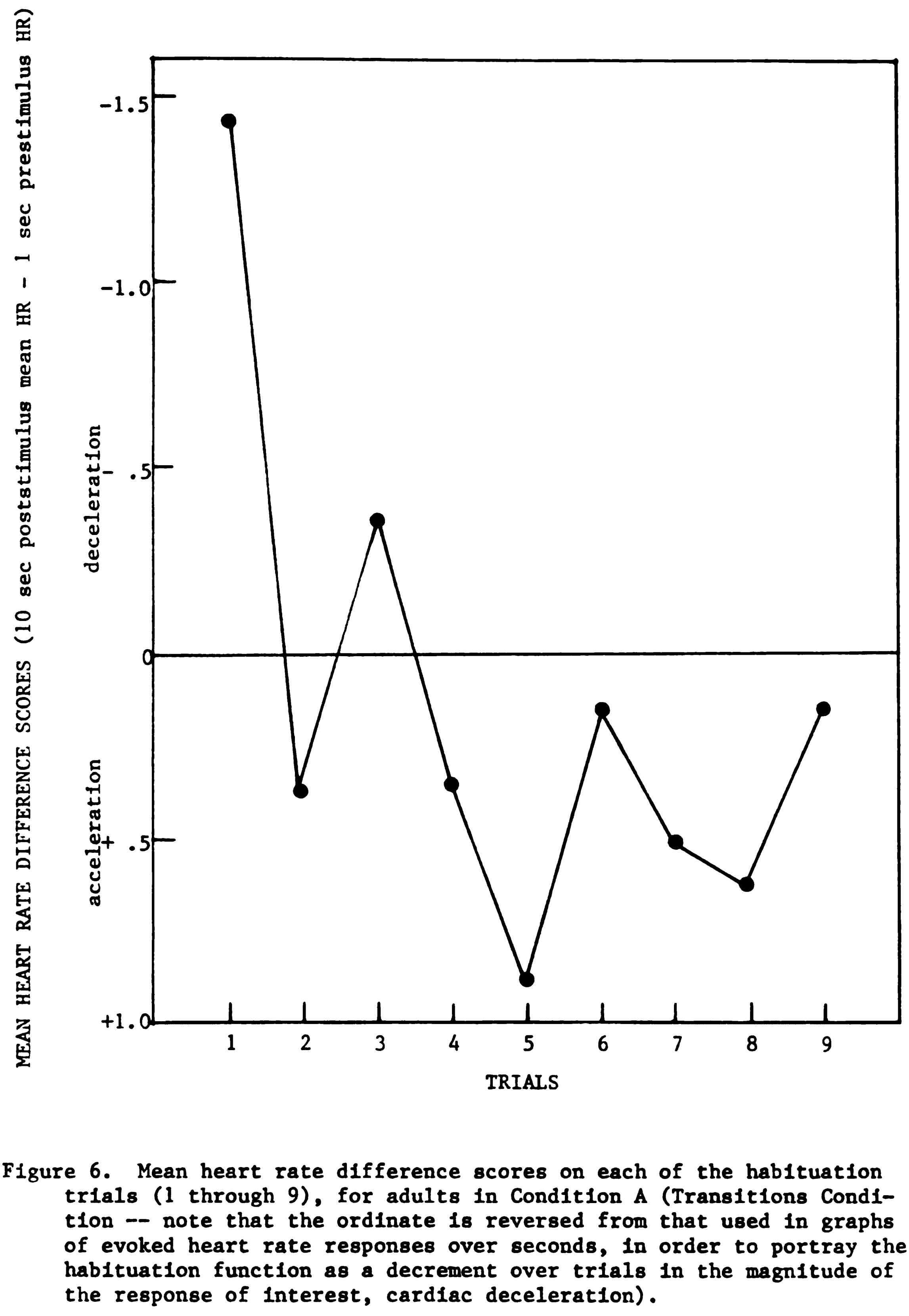


Figure 6. Mean heart rate difference scores on each of the habituation trials (1 through 9), for adults in Condition A (Transitions Condition -- note that the ordinate is reversed from that used in graphs of evoked heart rate responses over seconds, in order to portray the habituation function as a decrement over trials in the magnitude of the response of interest, cardiac deceleration).

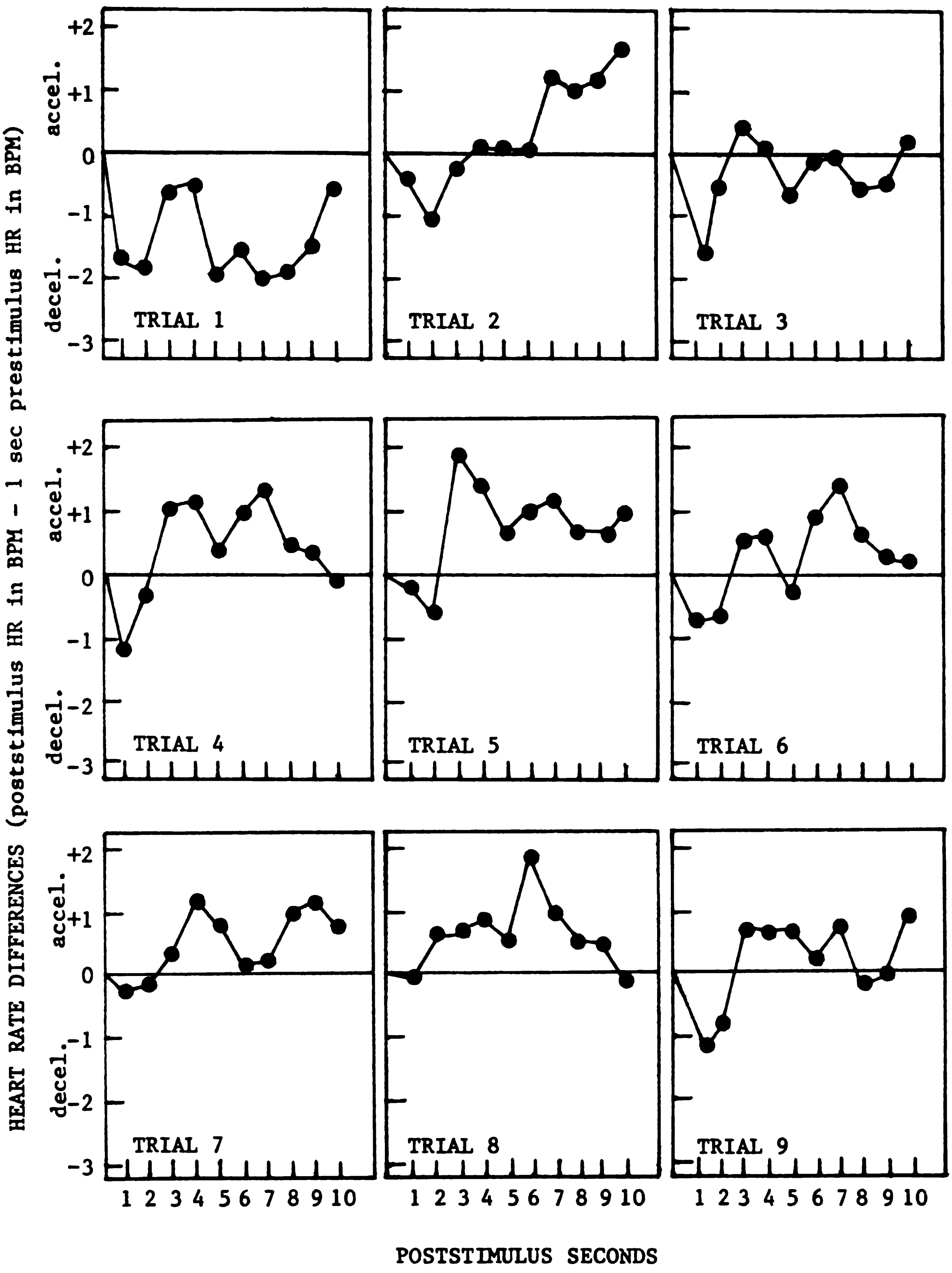


Figure 7. Second-by-second evoked poststimulus heart rate responses on each of the habituation trials (1 through 9), for the adults in Condition A (Transitions Condition).

during the habituation trials. These latter two findings from the analysis of trials 1 through 9 provide only weak evidence that the adults in Condition A habituated to the dichotic habituation stimuli. However, the ANOVA on data from trials 1 and 9 alone reveal a significant Trials main effect, $F(1, 14) = 5.00$, $p < .04$, indicating a larger cardiac deceleration on trial 1 than on trial 9. Furthermore, a nonsignificant Seconds main effect on trial 9 alone suggests a lack of reliable cardiac deceleration on that trial, the last of the habituation trials for all four tests. There is sufficient evidence for habituation during trials 1 through 9 among the adults in Condition A, in that they showed some cardiac orienting to the dichotic habituation syllables early in the habituation series, yet the magnitude of the cardiac response had dropped to a nonsignificant level by trial 9. Therefore, a cardiac deceleration on trial 10 for any of the four dichotic tests can be interpreted as evidence for cardiac OR dishabituation, and as evidence for discrimination of the trial 10 novel stimulus from the dichotic habituation syllables.

Test trial analyses.--The analyses of the data for trials 9 and 10 indicate that significant trial 10 dishabituation occurred among adults in Condition A only for the vowel discrimination tests (see Figure 8), according to the Trials x Phoneme interaction , $F(1, 14) = 5.29$, $p < .04$, and the Seconds x Trials x Phoneme interaction, $F(9, 126) = 3.04$, $p < .003$. That is, recovery of the cardiac OR on trial 10, after habituation and no cardiac OR on trial 9, occurred only for vowel discrimination tests. Simple effects tests of the Trials x Phoneme interaction revealed that cardiac dishabituation on

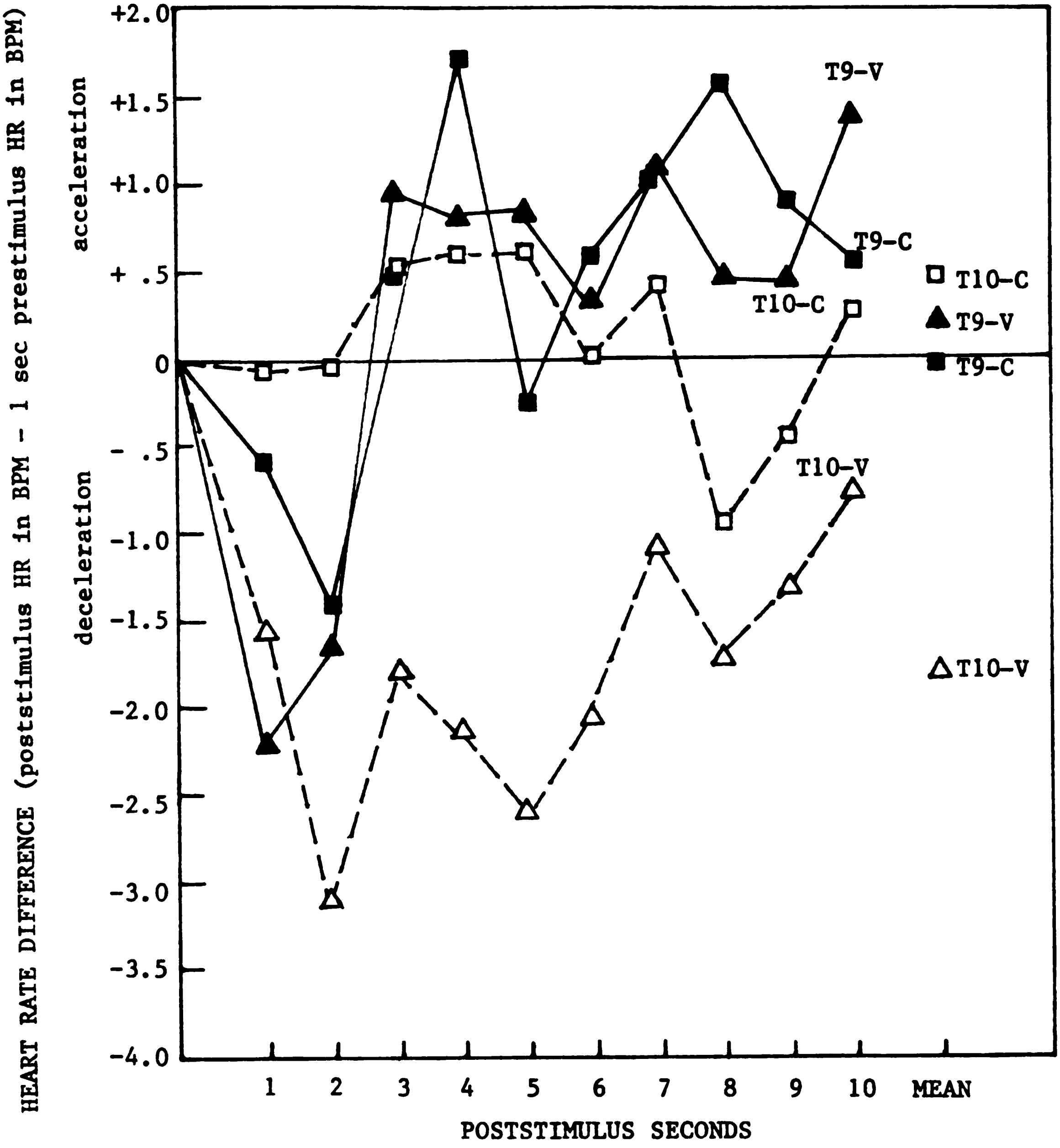


Figure 8. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores, on trials 9 (T9) and 10 (T10) during the Consonant (C) and Vowel (V) tests, for the adults in Condition A.

trial 10 relative to trial 9 had in fact occurred only for dichotic vowel discrimination tests, $F(1, 28) = 30.56$, $p < .002$, and not for dichotic consonant discrimination tests. Since the ANOVA for Trial 9 alone yielded nonsignificant seconds and phoneme main effects, and therefore lack of a reliable cardiac OR, the trials 9 and 10 ANOVA interactions involving the Seconds factor reflect some pattern of trial 10 deceleration. A significant Seconds effect on trial 10, $F(9, 126) = 2.54$, $p < .01$, suggests that a reliable cardiac deceleration did occur on trial 10. The Phoneme main effect for trial 10, $F(1, 14) = 4.24$, $p < .059$, indicates that a relatively large magnitude cardiac deceleration occurred in response to novel vowel stimuli but not to novel consonant stimuli. There were no ear differences for the trial 10 cardiac responses to the novel dichotic stimuli for either phoneme type.

Generally, then, under the experimental conditions used in the current study adults could discriminate a change in the vowel of a pair of dichotic syllables containing formant transitions, but did not discriminate a consonant change in dichotic syllables containing formant transitions. There were no ear (cerebral hemisphere) differences in discrimination for either phoneme type. Furthermore, the subjects' verbal reports corroborated their cardiac responses (considered as a group rather than individually)--nearly all of the subjects reported hearing a stimulus change during the left-ear and right-ear dichotic vowel test sequences (14 for the left ear test, 14 for the right ear test; probability greater than chance in each case, $Z = 3.005$, $p < .01$), but only a few reported hearing a stimulus change in either of the dichotic consonant test sequences (6 for the left ear test; no different from chance, $Z = 1.002$, $p > .1$; and 3 for the right ear test; less than chance, $Z = -2.504$, $p < .05$). Whereas earlier research has found a right ear (left hemisphere) advantage for processing consonants in CV syllables containing formant transitions, the present findings provide no evidence either for adults' discrimination among consonants under the experimental conditions described, nor for any right ear advantage in consonant processing. However, previous reports of hemisphere equivalence in adults for processing vowels in syllables containing formant transitions were replicated in the current study.

Condition B (Transitionless Condition)

Habituation trials analyses.--The adults in Condition B showed a brief but reliable cardiac deceleration following dichotic stimulus presentations during the habituation trials, similar in form to that shown by the adults in Condition A. This Seconds main effect, $F(9, 126) = 5.76$, $p < .0005$, is illustrated in Figure 9. The Trials main effects for the ANOVAs on data from trials 1 through 9, $F(8, 112) = 3.00$, $p < .004$, and the data on trials 1 and 9 alone, $F(1, 14) = 13.66$, $p < .002$, indicate that the average magnitude of the poststimulus cardiac deceleration decreased reliably from the first to the last habituation trial (see Figure 10). As can be seen in Figure 11, the Seconds x Trials interaction for the analysis of trials 1 through 9 was nonsignificant because the general form of the second-by-second poststimulus cardiac response was roughly similar for all habituation trials even though the mean response magnitude differed among the trials. The Trials effects, along with a nonsignificant deceleration on trial 9 alone (Seconds effect: n.s.), support the conclusion that the adults in

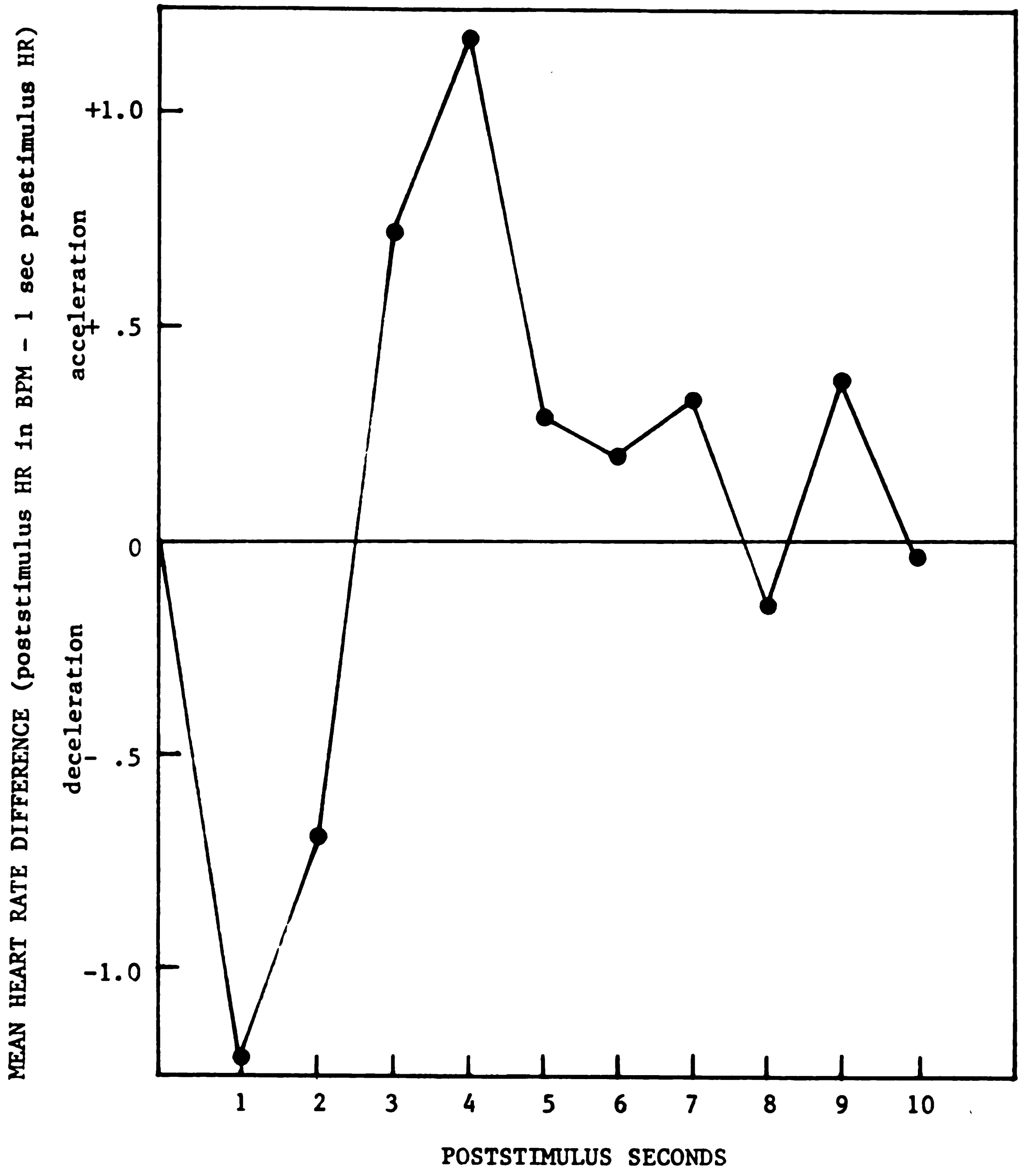


Figure 9. Second-by-second evoked poststimulus heart rate response, averaged over the habituation trials (1 through 9), for the adults in Condition B(Transitionless Condition).

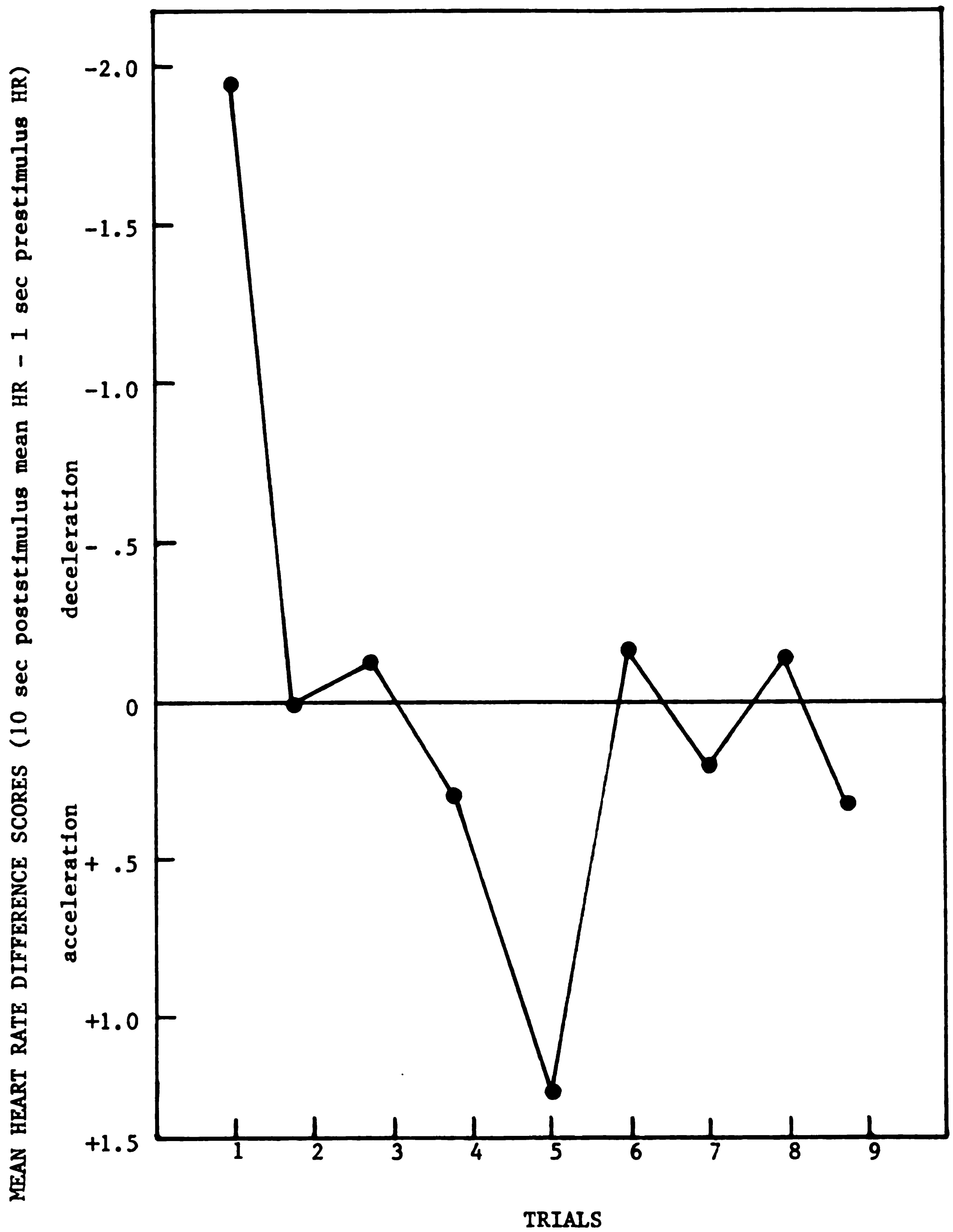


Figure 10. Mean heart rate difference scores on each of the habituation trials (1 through 9) for adults in Condition B (Transitionless Condition — note that ordinate is reversed from that used for graphs of evoked heart rate response over seconds).

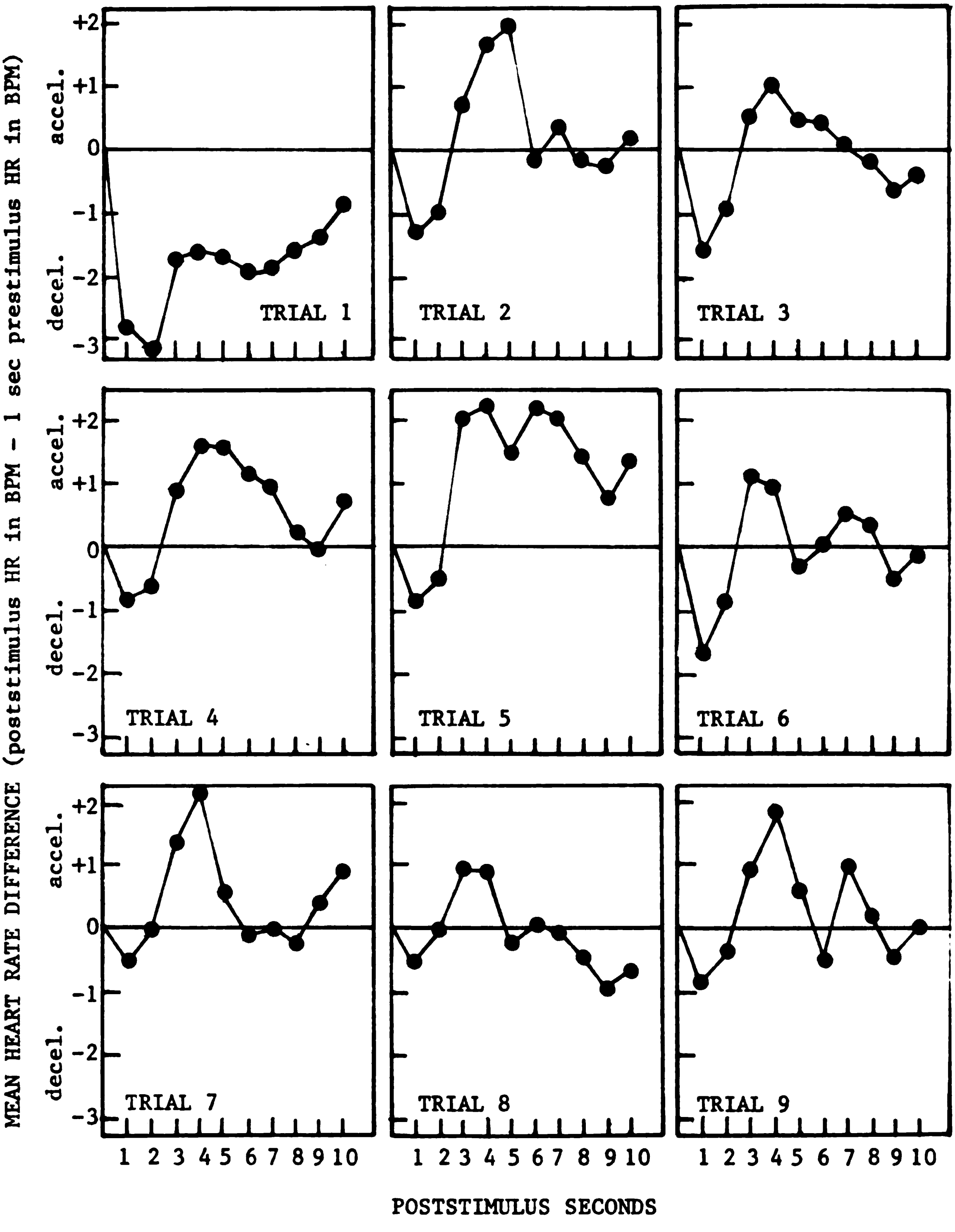


Figure 11. Second-by-second evoked poststimulus heart rate responses on each of the habituation trials (1 through 9), for the adults in Condition B (Transitionless Condition).

Condition B showed habituation of the cardiac response during the habituation trials of the four dichotic discrimination tests.

Test trial analyses.--As was just discussed, the ANOVA of data for trial 9 failed to show a reliable cardiac deceleration, which suggests that the cardiac OR had habituated by trial 9. When compared to the lack of consistent cardiac deceleration on trial 9, the significant Seconds effect on trial 10 alone, $F(9, 126) = 2.26$, $p < .022$, indicates that there was general dishabituation of cardiac orienting on the test trial, across the four dichotic tests. As with the adults in Condition A, a Condition B trial 10 Phoneme effect, $F(1, 14) = 6.02$, $p < .03$, indicates that dishabituation occurred for only the dichotic vowel discrimination tests and not for consonant discrimination tests (see Figure 12). Again, as in Condition A, the subjects' verbal reports corresponded to the pattern of their trial 10 cardiac responses. Many reported hearing a stimulus change during the dichotic vowel discrimination sequences (12 for the left ear test; greater than chance, $Z = 2.003$, $p < .05$; 15 for the right ear test; greater than chance, $Z = 3.506$, $p < .005$), but few reported hearing a change during the dichotic consonant discrimination tests (2 for the left ear test; less than chance, $Z = -3.005$, $p < .01$; 6 for the right ear test; no different from chance, $Z = 1.001$, $p > .1$). The Condition B test trial analyses provided no evidence of ear differences in the trial 10 cardiac responses for stimulus changes of either phoneme type.

The results for the adults in Conditions A and B are virtually identical. In both cases, adults showed a small cardiac OR which habituated during the first nine trials. The test trial dishabituations

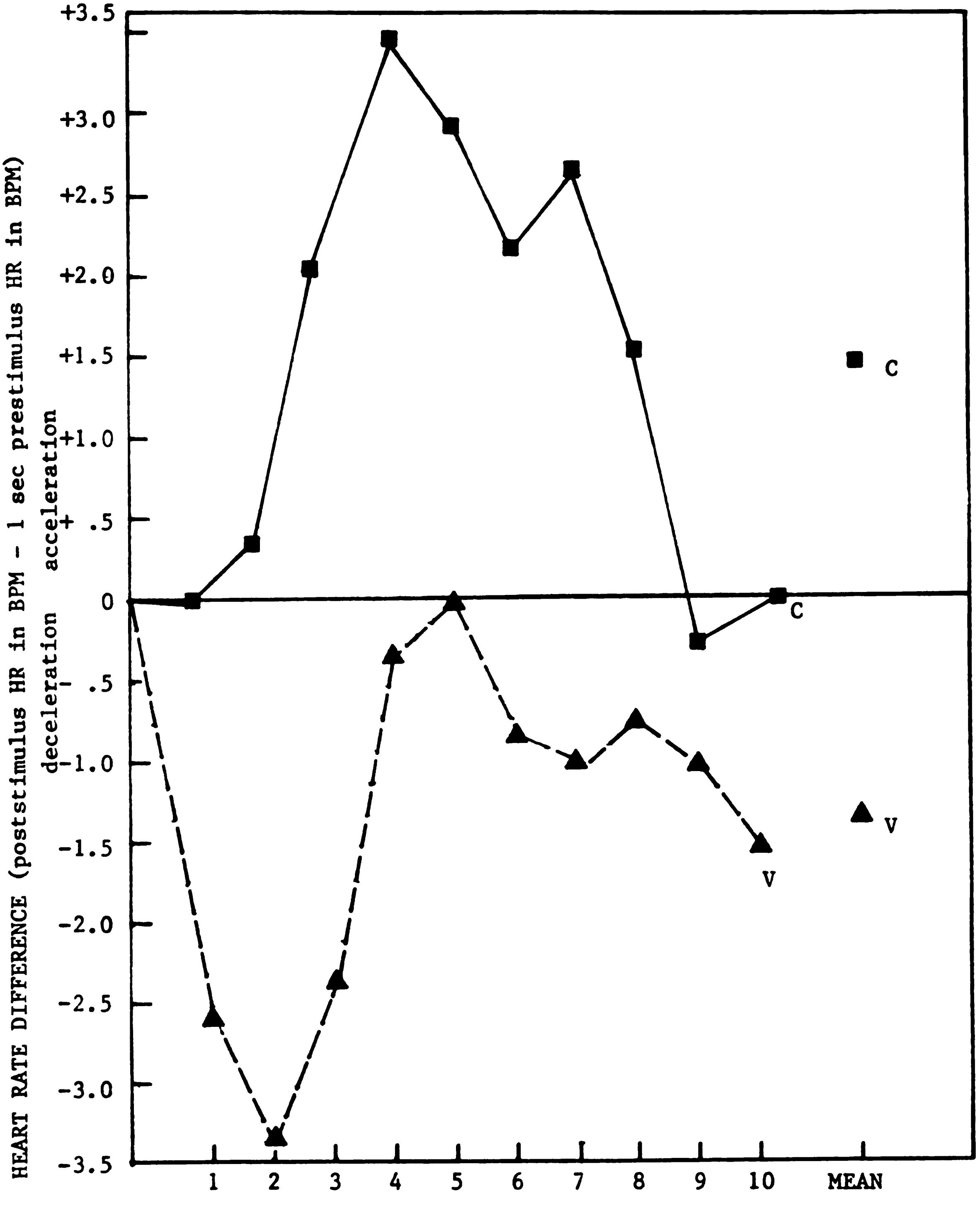


Figure 12. Second-by-second poststimulus heart rate responses on trial 10, and mean heart rate difference scores, for the Vowel (V) and Consonant (C) tests, for the adults in Condition B (Transitionless Condition).

in both conditions provided evidence neither for dichotic consonant discrimination, nor for hemisphere asymmetry in vowel or consonant discriminations, under the conditions of the current experiment. These findings reflect adult performance in a task as similar as possible to the dichotic task presented to the infant subjects. Since this adult research differs somewhat in both method and outcome from previous reports of adult dichotic abilities, the findings just reported provide a more appropriate basis than the previous research for consideration of the infant results.

Infants

The analyses of the total data set for all infants failed to reveal evidence for significant habituation of cardiac orienting in either experimental Condition A or B. Because the experimental hypotheses regarding hemispheric asymmetries for consonant and vowel discrimination required that habituation occur by trial 9 of the four tests in order that ear and phoneme differences in trial 10 dishabituation could be tested, the analyses for the total sample could not be used to directly test predictions. However, since habituation was a prerequisite for making correct interpretations of the test trial (trial 10) results, yet would not directly affect the direction of test trial results, several analyses were performed on subsets of the data for infants who showed evidence of habituation by trial 9 (referred to subsequently as Group H infants, or "habituators"). A brief description of the major findings from the ANOVAs on the total sample of infants in Conditions A and B is described next, as a comparison basis for the Group H findings, after which the selection of subjects for Group H analyses is described along with the Group H results.

Total Sample of Infants

Condition A (Transitions Condition).--Habituation trials ANOVAs for the infants in Condition A yielded no evidence of habituation, as mentioned above, since the Trials main effect and Seconds x Trials interaction for the data on trials 1 through 9 and on trials 1 and 9 alone were nonsignificant. Lack of habituation did not result from a lack of cardiac orienting to the dichotic stimulus presentations, however. A significant trials 1 through 9 Seconds effect, $F(9, 126) = 2.12$, $p < .025$, provides evidence for reliable poststimulus cardiac deceleration across the habituation trials. The lack of habituation is at least partly attributable to a reliable cardiac deceleration on trials 1 and 9, reflected in the Seconds main effect, $F(9, 126) = 2.17$, $p < .03$, which did not differ in form or magnitude for the two trials. As would be expected from the latter finding, the Seconds main effect on trial 9 alone, $F(9, 126) = 2.20$, $p < .03$, indicates a reliable cardiac deceleration.

The test trials analyses yielded several significant interactions. A Seconds x Trials x Phoneme interaction for trials 9 and 10, $F(9,126) = 2.01$, $p < .04$, provides some evidence of trial 10 dishabituation relative to trial 9 for dichotic consonant discrimination tests, but no evidence of dishabituation for vowel discrimination tests because of a large trial 9 deceleration during the vowel dichotic test sequences (see Figure 13). The Trials x Gender x Phoneme interaction on trials 9 and 10, $F(1, 14) = 6.76$, $p < .02$, and the trial 10 Gender x Phoneme interactions, $F(1, 14) = 6.87$, $p < .02$, indicate trial 10 dishabituation only for males during dichotic consonant discriminations

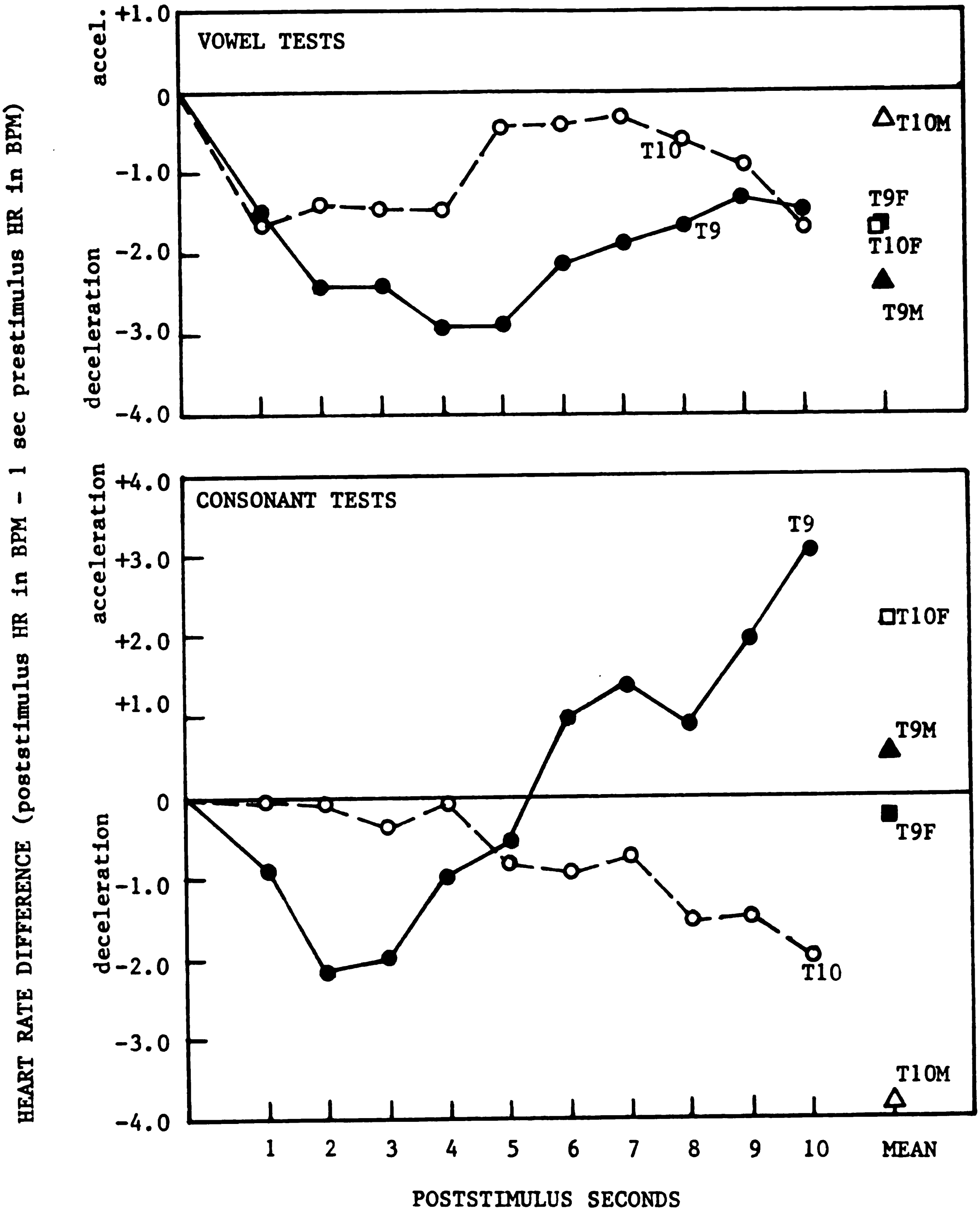


Figure 13. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores for males (M) and females (F), during Vowel (V) and Consonant (C) tests on trials 9 (T9) and 10 (T10), for the total sample of infants in Condition A (Transitions Condition).

(refer again to Figure 13). Simple effects tests revealed a significant sex difference favoring males in the magnitude of the trial 10 cardiac deceleration during dichotic consonant tests, $F(1, 28) = 9.55$, $p < .01$. There were no ear effects in the Condition A test trial analyses. And since habituation did not occur for the total sample of infants in Condition A, it is difficult to interpret the test trial results straightforwardly.

Condition B (Transitionless Condition).--The major results of the habituation trials analyses for infants in Condition B are similar to the Condition A results. A significant Seconds effect, for trials 1 through 9, $F(9, 126) = 7.24$, $p < .0005$, provides evidence of post-stimulus cardiac deceleration across the habituation trials, although nonsignificant Trials and Seconds x Trials effects fail to support the occurrence of reliable habituation. Furthermore, significant Seconds main effects for trials 1 and 9, $F(9, 126) = 3.3$, $p < .001$, and for trial 9 alone, $F(9, 126) = 4.33$, $p < .0005$, indicate that reliable cardiac orienting occurred on both trials.

Test trial analyses for Condition B infants revealed some evidence for trial 10 dishabituation relative to trial 9 (Seconds x Trials: $F(9, 126) = 2.03$, $p < .04$). The magnitude of trial 10 cardiac deceleration was dependent on a Phoneme x Ear interaction, $F(9, 126) = 4.66$, $p < .05$. Simple effects tests of the Phoneme x Ear interaction supported a right ear advantage in the magnitude of the trial 10 deceleration during consonant discrimination tests, $F(1, 28) = 7.67$, $p < .01$, and a nonsignificant left ear advantage for vowel discrimination tests (see Figure 14). However, as discussed earlier, interpretation of these

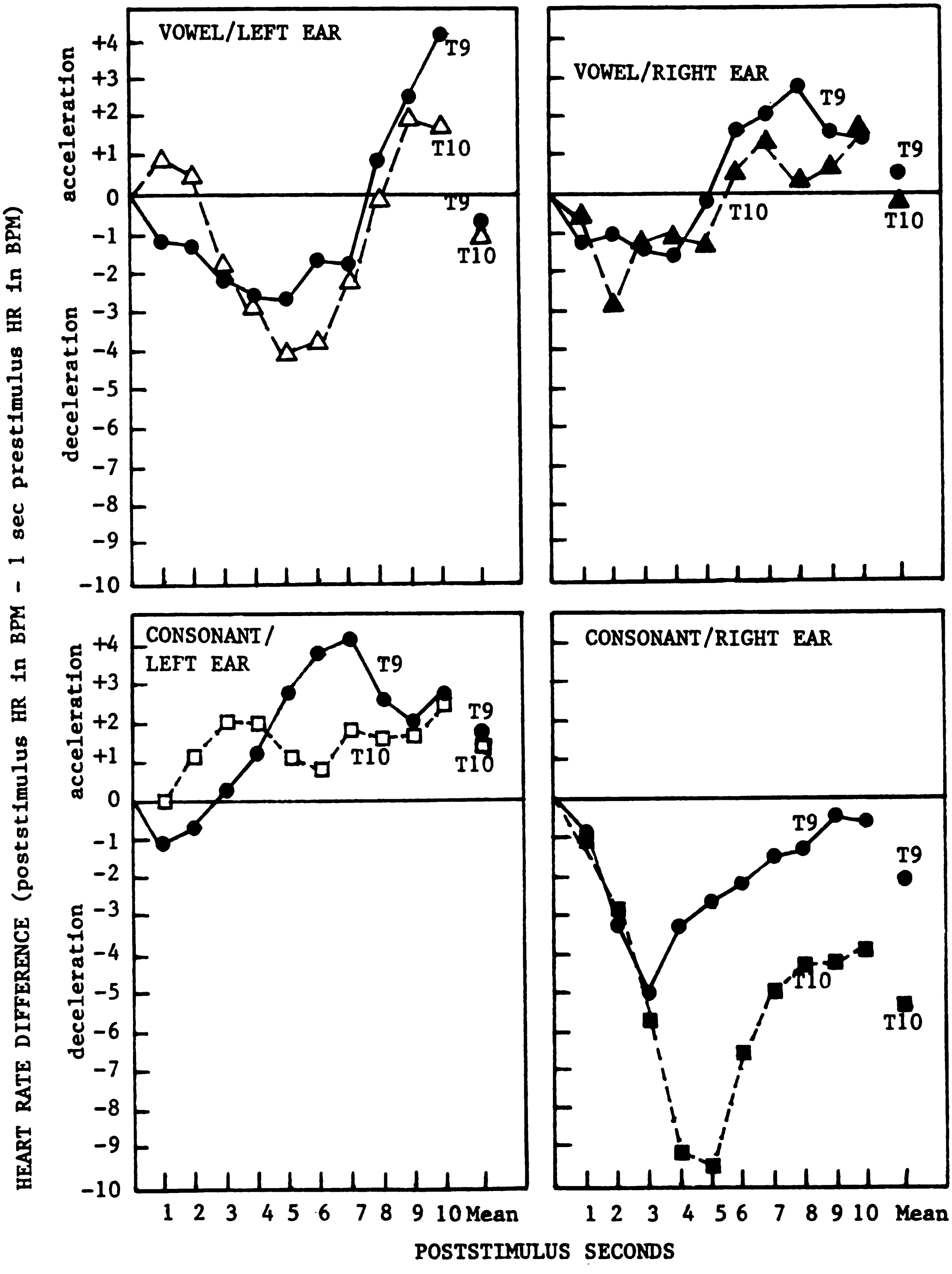


Figure 14. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores on trials 9 and 10, during Left Ear (L) and Right Ear (R) tests of Consonant (C) and Vowel (V) discrimination, for the total sample of infants in Condition B (Transitionless Condition).

Condition B test trial findings is confounded by lack of habituation by the last habituation trial.

Analyses of Infants in Group H ("Habituators")

Because the lack of cardiac habituation for the total sample of infants in Conditions A and B made interpretation of test trial results difficult, the cardiac responses of individual infants on trials 1 through 9 were studied to assess whether habituation may have occurred in a large enough subgroup of subjects to run separate analyses. To be considered as a possible "habituator" (Group H), an individual had to show a cardiac OR of fairly regular form on several early trials during a given test sequence, but no deceleration on trial 9, or at least a smaller one. The author made this appraisal blind to Condition, Phoneme, and Ear factors. The appraisal of individual infants' responses suggested that for each of the four tests in each Condition, roughly 2/3 of the subjects showed cardiac orienting which had habituated by trial 9 (range = 10-13 subjects habituated in any given test, of a possible 16). After individuals had been chosen for Group H analyses, their test trial (trial 10) second-by-second cardiac responses were studied (again blind to Condition, Phoneme and Ear) and categorized as showing evidence for dishabituation (larger deceleration on trial 10 than trial 9) or failure to dishabituate (smaller deceleration on trial 10 than trial 9, but usually a trial 10 cardiac acceleration). Nearly all of the trial 10 responses of the group H infants were easily classified as clearly showing or failing to show dishabituation.

The Group H subsets of the infant data for each Condition were submitted to separate ANOVAs. Most of the thirty-two individual infants showed habituation on some but not all of the tests in which they had participated, although the occurrence of habituation was not clearly related to the order of the tests in the session, to the phoneme type (vowel or consonant discrimination test sequences), or to the infant's biobehavioral state during the tests. Only two of the subjects showed no evidence of habituation on any of the four tests, while eight showed evidence of habituation on all four tests. For that reason, the Group H ANOVAs for both Conditions were set up so as to treat the data from each of the four tests (Consonant/Left Ear, Consonant/Right Ear, Vowel/Left Ear, Vowel/Right Ear) as though they were from separate but overlapping groups of infant subjects. That is, Phoneme and Ear were lost as repeated-measures factors; instead, subjects were considered to be nested within Phoneme and Ear factors. In addition, the reduction in the number of subjects and the loss of equal cell sizes required that the Gender factor be dropped from these analyses. The number of cases in each test for each Condition is listed in Table 4. Refer to Appendix H, Table H1, for listings of the mean heart rate difference scores on trials 9 and 10 for all subjects, and for identification of Group H infants as well as designation of each Group H infant as to whether he showed trial 10 dishabituation.

Condition A (Transitions Condition)

Habituation trials analyses.--The ANOVA on the data from trials 1 through 9 for Group H infants in Condition A revealed a significant Trials effect, $F(8, 312) = 2.08$, $p < .04$, which is illustrated in Figure 15. The Seconds main effect shown in Figure 16, $F(9, 351) = 3.42$, $p < .0005$, indicates that significant poststimulus cardiac

Table 4. The number of cases in each of the four dichotic tests in Conditions A and B, for analyses of Group H ("habituators") infants. Amount of overlap for cases among the four dichotic tests is also noted.

		Vowel/ Left Ear Test (VLE):	Vowel/ Right Ear Test (VRE):	Consonant/ Left Ear Test (CLE):	Consonant/ Right Ear Test (CRE):
Condition A: (Transitions Condition)	N=	10	11	12	13
		5 in VRE,CLE & CRE 2 in VRE & CLE 1 in VRE & CRE 2 in CLE & CRE	5 in VRE,CLE & CRE 2 in VLE & CLE 1 in VLE & CRE 1 in CRE 1 in CLE	5 in VLE,VRE & CRE 2 in VLE & & CRE 2 in VLE & VRE 1 in VRE & CRE 1 in VRE 1 in CLE only	5 in VLE,VRE & CLE 2 in VLE & CLE 1 in VLE & VRE 1 in VRE & CLE 1 in VRE
Condition B: (Transitionless Condition)	N=	11	11	13	11
		3 in VRE,CLE & CRE 4 in VRE & CLE 2 in CLE & CRE 1 in VRE & CRE 1 in CRE	3 in VLE,CLE & CRE 4 in VLE & CLE 1 in CLE & CRE 1 in CRE 1 in CLE 1 in VLE & CRE	3 in VLE,VRE & CRE 4 in VLE & VRE 2 in VLE & CRE 1 in VLE 2 in CRE	3 in VLE,VRE & CLE 1 in VLE & VRE 2 in VLE & CLE 1 in VRE & CRE 1 in VLE 2 in CRE 1 in VRE

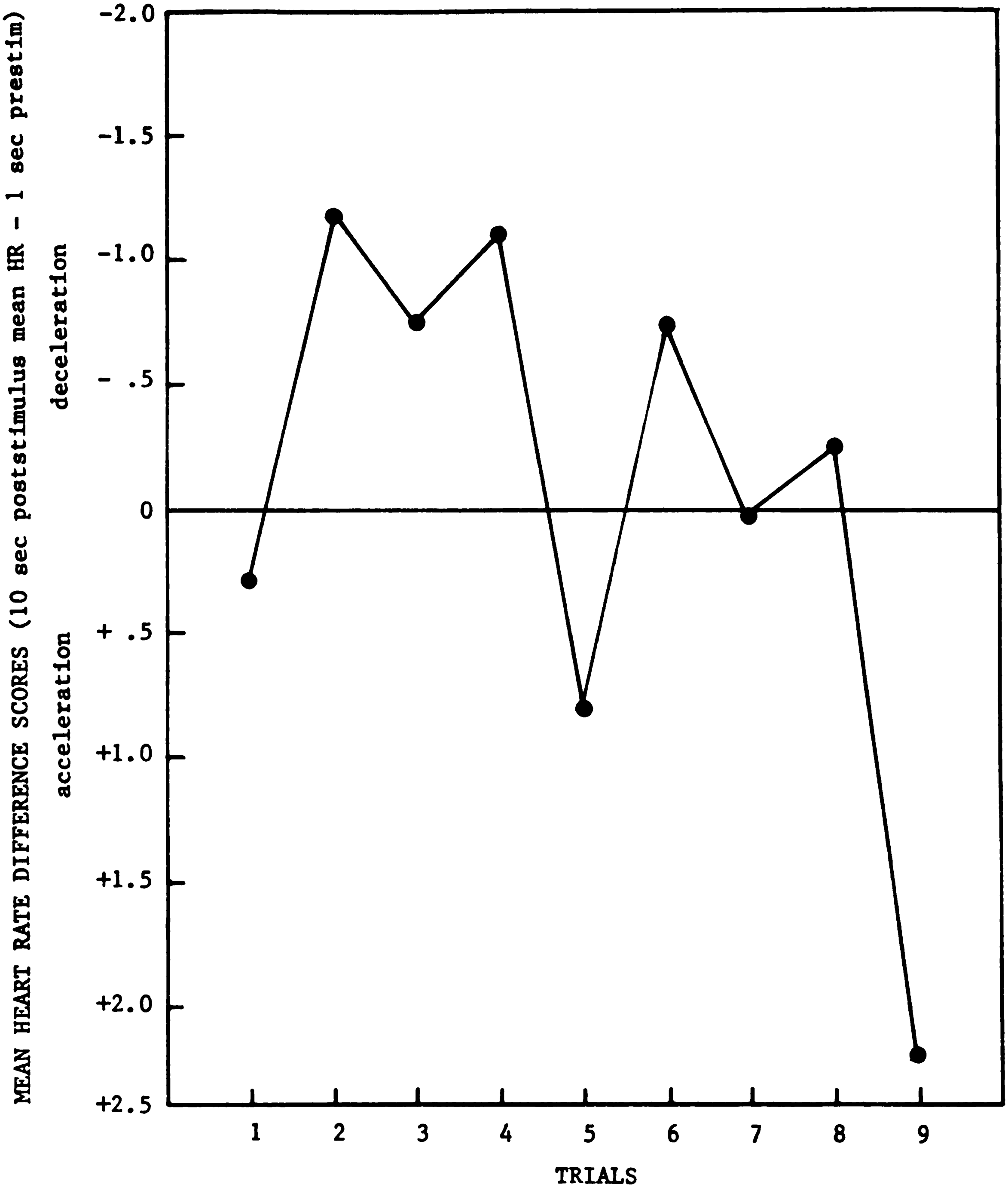


Figure 15. Mean heart rate difference scores on each of the habituation trials (1 through 9), for Group H infants in Condition A (Transitions Condition -- note that ordinate is reversed from that used for graphs of evoked heart rate response over seconds).

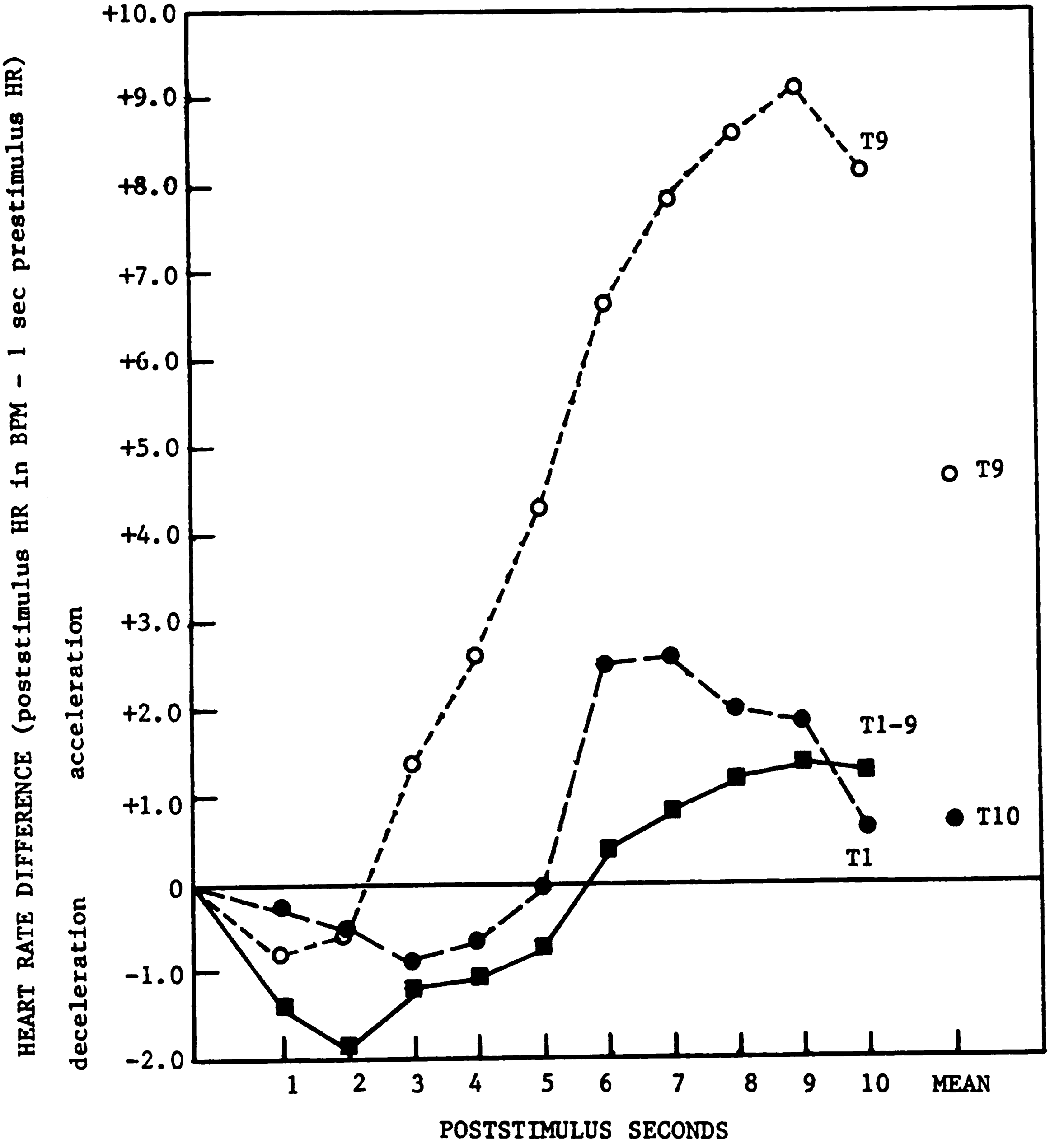


Figure 16. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores, during habituation trials 1 (T1) and 9 (T9), and averaged across all habituation trials (T1-9), for the Group H infants in Condition A (Transitions Condition).

deceleration occurred across the nine habituation trials of all four dichotic tests. As can be seen in Figure 17, the nonsignificant Seconds x Trials interaction suggests that the general second-by-second form of the poststimulus cardiac response did not change significantly from trial to trial during the first nine trials of the tests, although the average magnitude of the heart rate responses did show habituation. Further support for habituation was found in the trials 1 and 9 analyses. Although the Seconds effect, $\underline{F}(9, 351) = 5.83$, $\underline{p} < .0005$, suggests that the general second-by-second form of the poststimulus cardiac response on those two trials was similar (small deceleration followed by a larger acceleration and then the beginning of a return to the prestimulus baseline heart rate), the Trials main effect, $\underline{F}(1,39) = 4.31$, $\underline{p} < .044$, and the Seconds x Trials interaction, $\underline{F}(9, 351) = 2.81$, $\underline{p} < .003$, provide evidence that habituation had occurred by trial 9; that is, the trial 9 acceleration was larger than that on trial 1. Cardiac acceleration to the last stimulus presentation(s) in a habituation sequence is commonly interpreted as reflecting lack of cardiac orienting; in other words, it is congruent with the interpretation of habituation. Figure 16 shows a larger trial 9 than trial 1 poststimulus cardiac acceleration, suggesting again that habituation had occurred by trial 9. In addition, the analysis of trial 9 alone revealed a significant Seconds effect, $\underline{F}(9, 351) = 7.96$, $\underline{p} < .0005$, reflecting that the second-by-second cardiac acceleration on trial 9 was reliable in form, again supporting habituation.

Test trial analyses.--Analyses of the trials 9 and 10 data for Group H infants in Condition A yielded evidence for trial 10

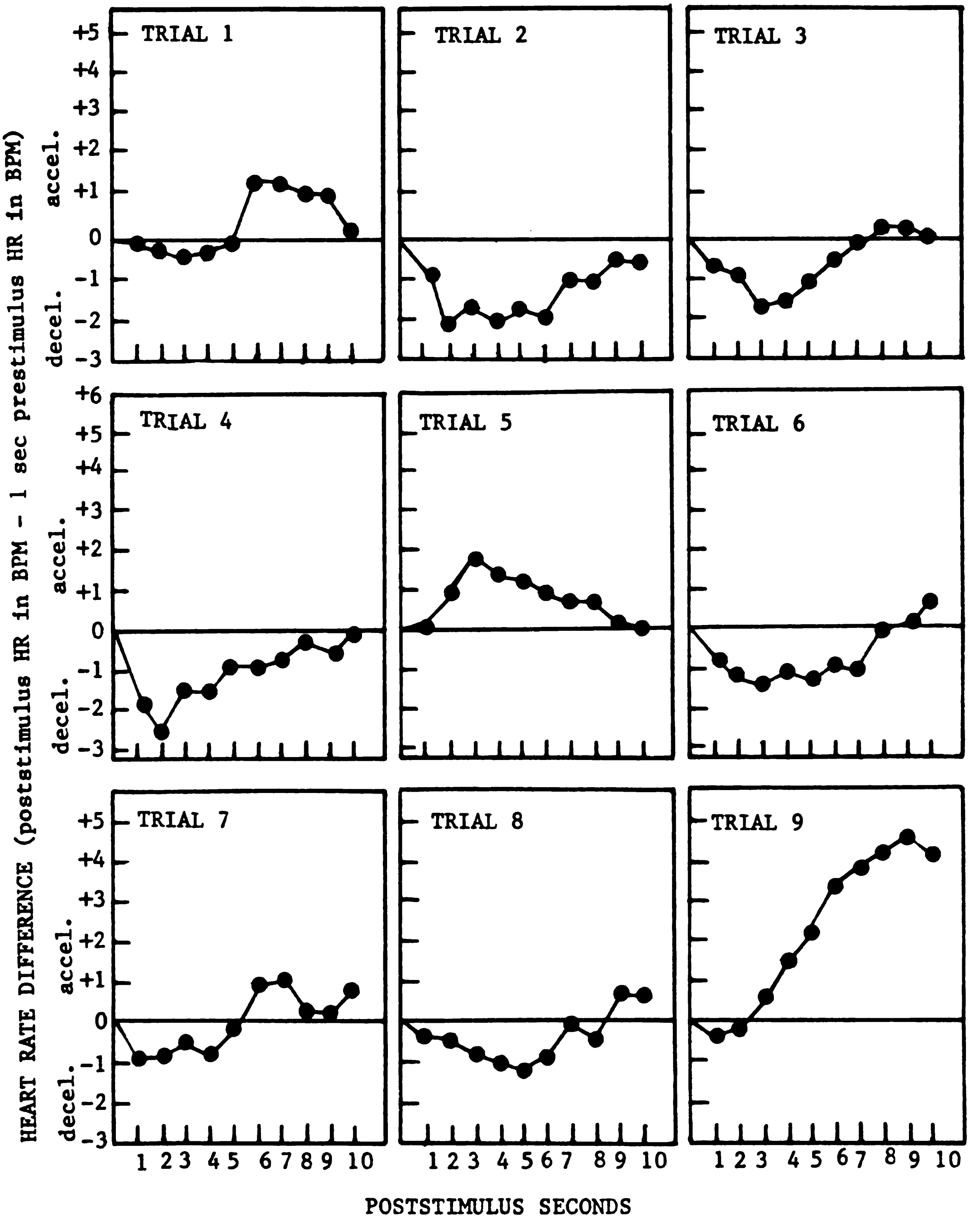


Figure 17. Second-by-second evoked poststimulus heart rate responses on each of the habituation trials (1 through 9), for the Group H infants in Condition A (Transitions Condition).

dishabituation relative to trial 9, as can be seen in Figure 18 (Trials main effect: $\underline{F}(1,39) = 10.48$, $\underline{p} < .002$; Seconds x Trials interaction: $\underline{F}(9, 351) = 6.85$, $\underline{p} < .0005$). There were no significant Ear or Phoneme effects, suggesting no reliable hemisphere asymmetries or differences between phoneme types in magnitude of dishabituation (see Figure 18). The trials 9 and 10 findings suggest that the infants discriminated vowel and consonant stimulus changes, and did so equally well with the two ears. However, failure to find a significant Seconds effect on trial 10 alone implies that although the trial 10 cardiac response was reliably different from the trial 9 accelerative response, it was not itself a reliable deceleration.

An additional check of the pre-analysis designation of the Condition A infants in Group H according to whether they showed trial 10 dishabituation relative to their trial 9 cardiac response (see Appendix G, Table G1) indicated that about half the subjects in each of the four dichotic tests clearly dishabituated, whereas the other half in each test clearly failed to dishabituate. That is, it did not appear that failure to find reliable trial 10 deceleration resulted from an approximately equivalent lack of clear deceleration among most of the infants. Instead, it seemed that some infants showed large trial 10 decelerations while others showed primarily trial 10 accelerations, with very little overlap between the two groups in the distribution of forms of the trial 10 cardiac response. Further statistical analyses which included the prior designation of subjects as "dishabituators" (Subgroup D) or "nondishabituators" (Subgroup N) as an additional two-level random ANOVA factor supported the suggestions just made. As can be seen in Figure 19, the trials 9 and 10 analyses found that Subgroup D

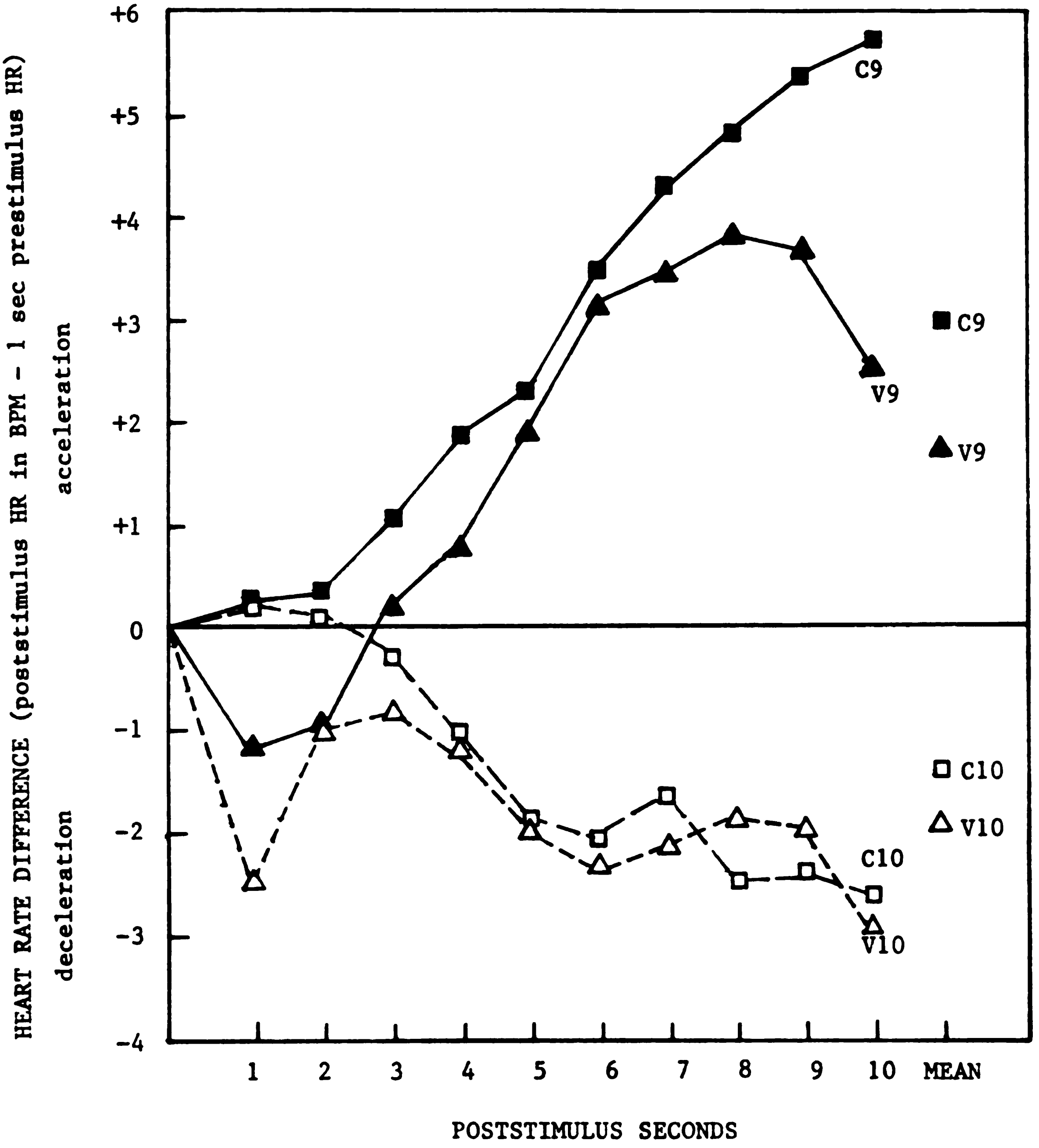


Figure 18. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores, on trials 9 (9) and 10 (10), during Consonant (C) and Vowel (V) tests, for Group H infants in Condition A (Transitions Condition).

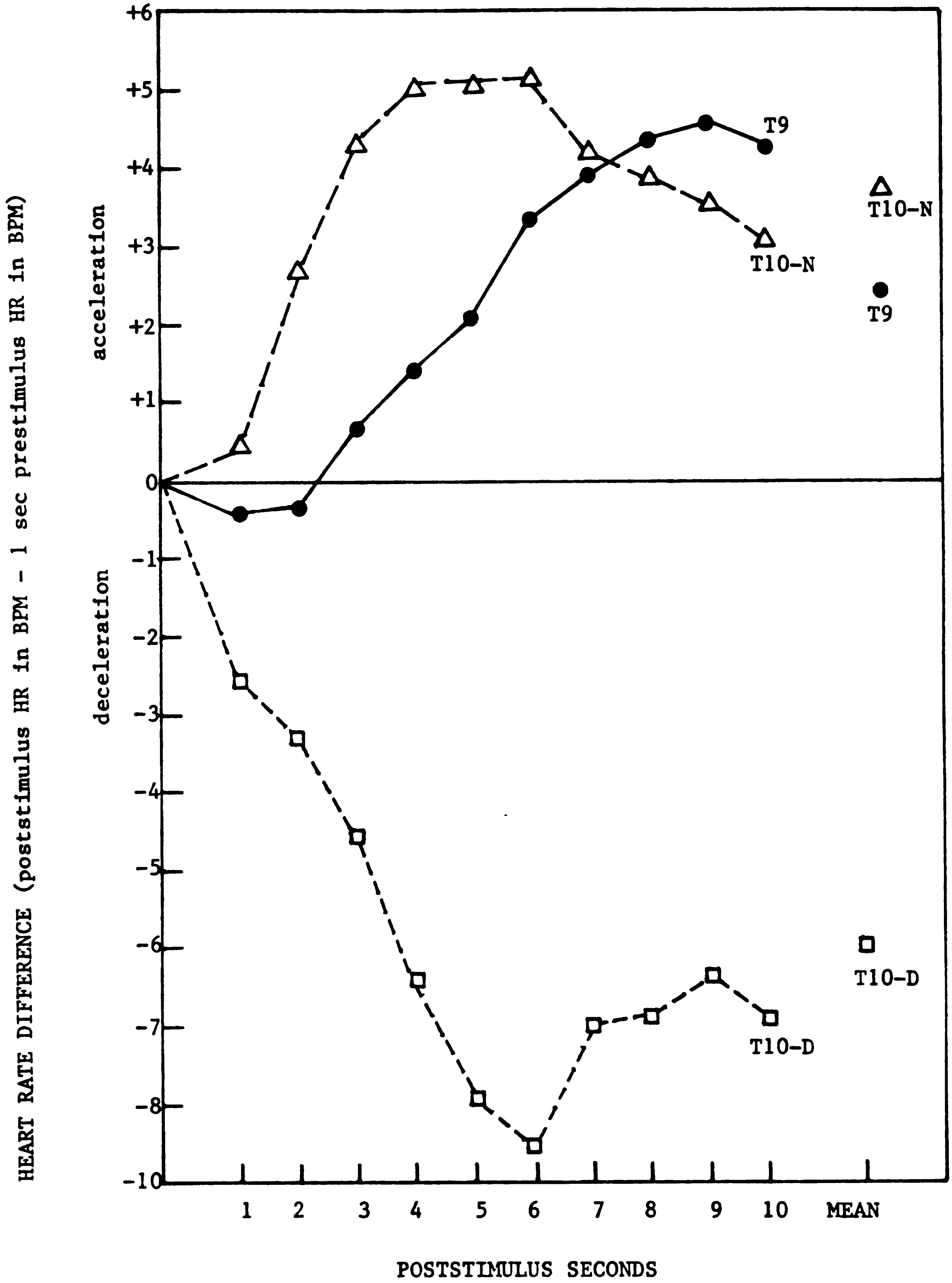


Figure 19. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores, on trials 9 (T9) and 10 (T10), in the Dishabituation (D) and Nondishabituation (N) subgroups of the Group H infants in Condition A (Transitions Condition).

infants showed a clear, reliable cardiac deceleration on trial 10 relative to trial 9, whereas the Subgroup N infants showed similar cardiac acceleration on both trials (Trials x Subgroups interaction: $F(1, 35) = 19.77$, $p < .0005$; Seconds x Trials x Subgroups interaction: $F(9, 315) = 5.82$, $p < .0005$). Simple effects tests upheld the interpretation that dishabituation had occurred for Subgroup D, $F(1, 70) = 34.64$, $p < .0005$, but not for Subgroup N. Moreover, the trial 10 analysis on the data for the two subgroups showed a significant difference between the cardiac responses of the "dishabituators" and the "nondishabituators" (Subgroups: $F(1, 35) = 67.09$, $p < .0005$; Seconds x Subgroups: $F(9,315) = 5.02$, $p < .0005$), but no Ear or Phoneme differences in the magnitude of the trial 10 heart rate response for either subgroup (see Figure 20).

In summary, the test trial analyses for Group H infants in Condition A revealed that overall, these infants showed significant though weak evidence of dishabituation on trial 10, and that about half of the infants in each of the four dichotic discrimination tests showed reliable trial 10 cardiac decelerations to the stimulus change. There were no ear differences for these infants on either the vowel or the consonant discrimination tests. The Group H infants in Condition A are therefore similar to the adults in Condition A in that both groups of subjects showed equal magnitude cardiac dishabituations on trial 10 for both ear tests during the vowel discrimination sequences. However, unlike the Condition A adults in the current study, they showed evidence of discriminating the consonant change on the test trial. And unlike adults in previous studies, these infants provided no evidence of a significant right ear advantage for processing consonants in syllables containing formant transitions.

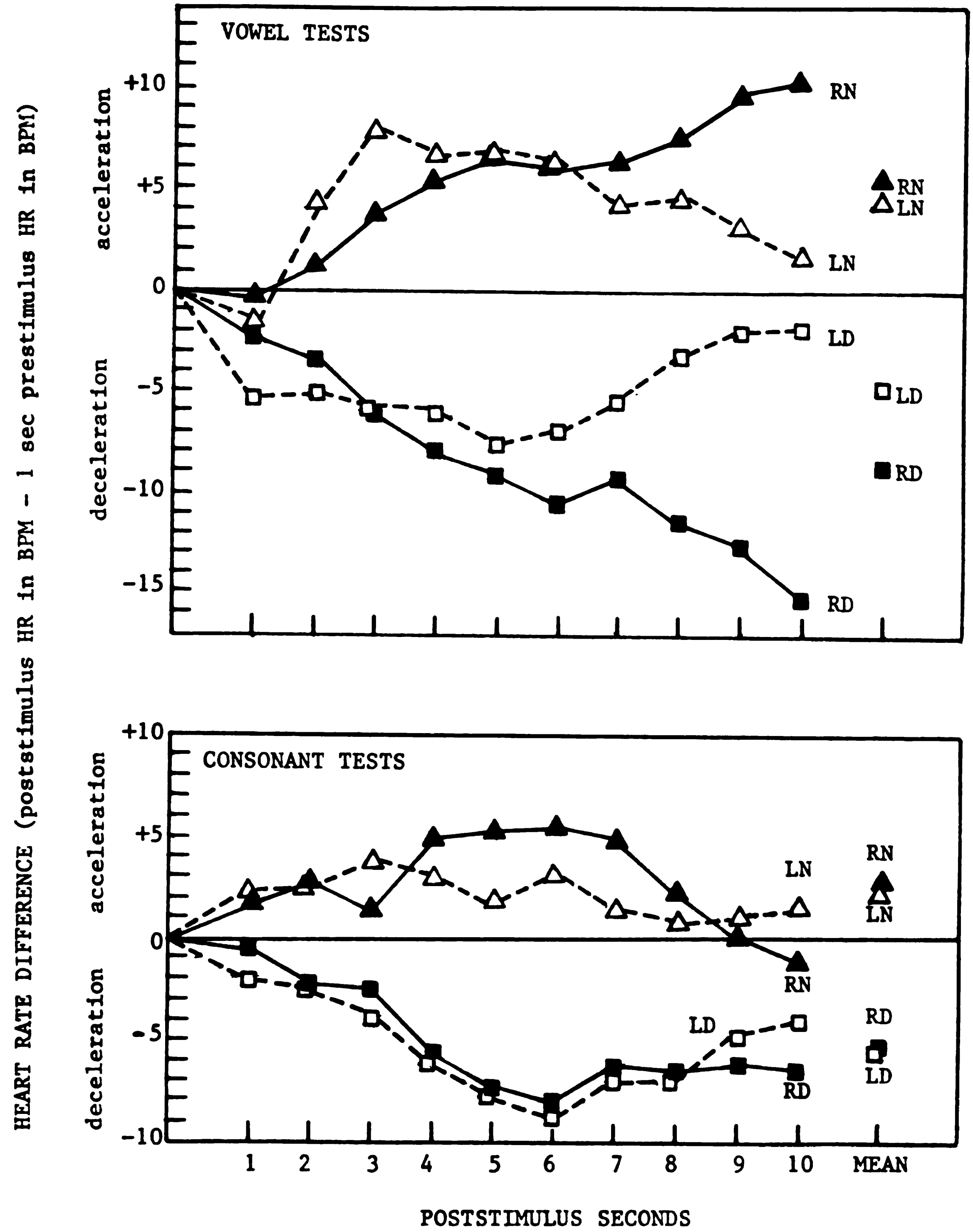


Figure 20. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores, during the Left Ear (L) and Right Ear (R) tests on trial 10, for the Dishabituation (D) and Nondishabituation (N) subgroups of the Group H infants in Condition A (Transitions Condition).

Condition B (Transitionless Condition)

Habituation trials analyses.--The ANOVA on the data for Group H infants in Condition B supported the notion that the magnitude of cardiac responses habituated during trials 1 through 9, as shown in Figure 21 (Trials: $F(8, 336) = 1.99$, $p < .046$). Summed across trials, the Seconds effect, $F(9, 378) = 7.75$, $p < .0005$, indicates that the second-by-second course of the poststimulus cardiac response was a reliable deceleration (see Figure 22). Lack of a significant Seconds x Trials interaction suggests that although the magnitude of the cardiac response changed over trials, the second-by-second form of the response was similar on all trials (see Figure 23). A significant Seconds effect on trial 9 alone, $F(9, 378) = 4.07$, $p < .0005$, indicating cardiac acceleration, provides further support for habituation of the cardiac OR by trial 9.

Test trial analyses.--Both a significant Trials main effect, $F(1, 42) = 10.52$, $p < .002$, and a Seconds x Trials interaction, $F(9, 378) = 4.70$, $p < .0005$, indicate that significant cardiac OR dishabituation occurred on trial 10 relative to the trial 9 cardiac response, for the Group H infants in Condition B. In addition, a significant Seconds effect for trial 10 alone, $F(9, 378) = 3.06$, $p < .002$, reflects that a reliable cardiac deceleration occurred on trial 10. Ear differences in magnitude of trial 10 dishabituation for vowel and consonant discrimination tests are illustrated in Figure 24, and are supported by a significant Phoneme x Ear interaction, $F(1, 42) = 5.84$, $p < .02$, as well as by a Seconds X Phoneme x Ear interaction, $F(9, 378) = 3.02$, $p < .002$.

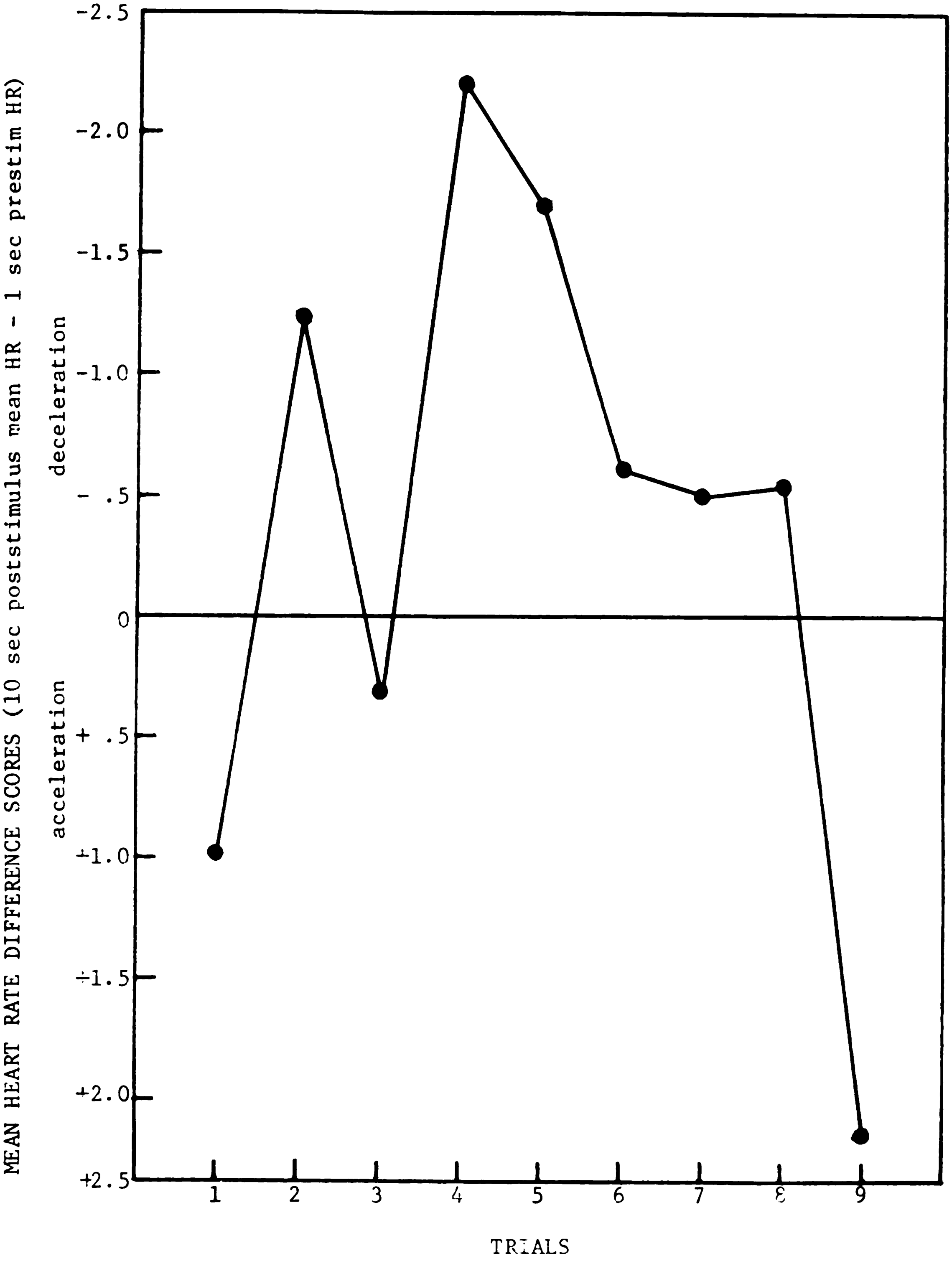


Figure 21. Mean heart rate difference scores on each of the habituation trials (1 through 9), for the Group H infants in Condition B (Transitionless Condition -- note that ordinate is reversed from that used for graphs of evoked heart rate response over seconds).

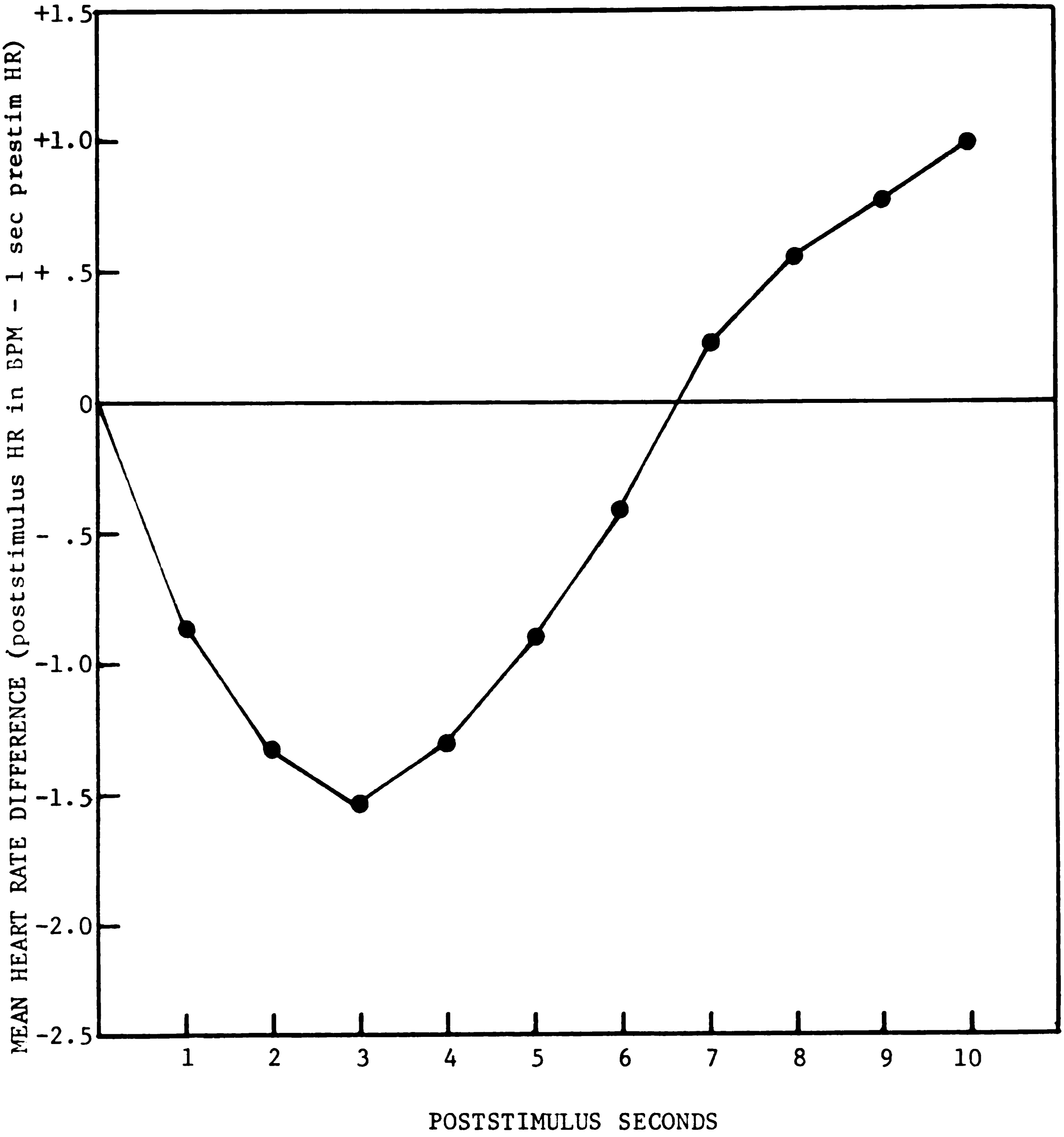


Figure 22. Second-by-second evoked poststimulus heart rate response, averaged over the habituation trials (1 through 9), for the Group H infants in Condition B (Transitionless Condition).

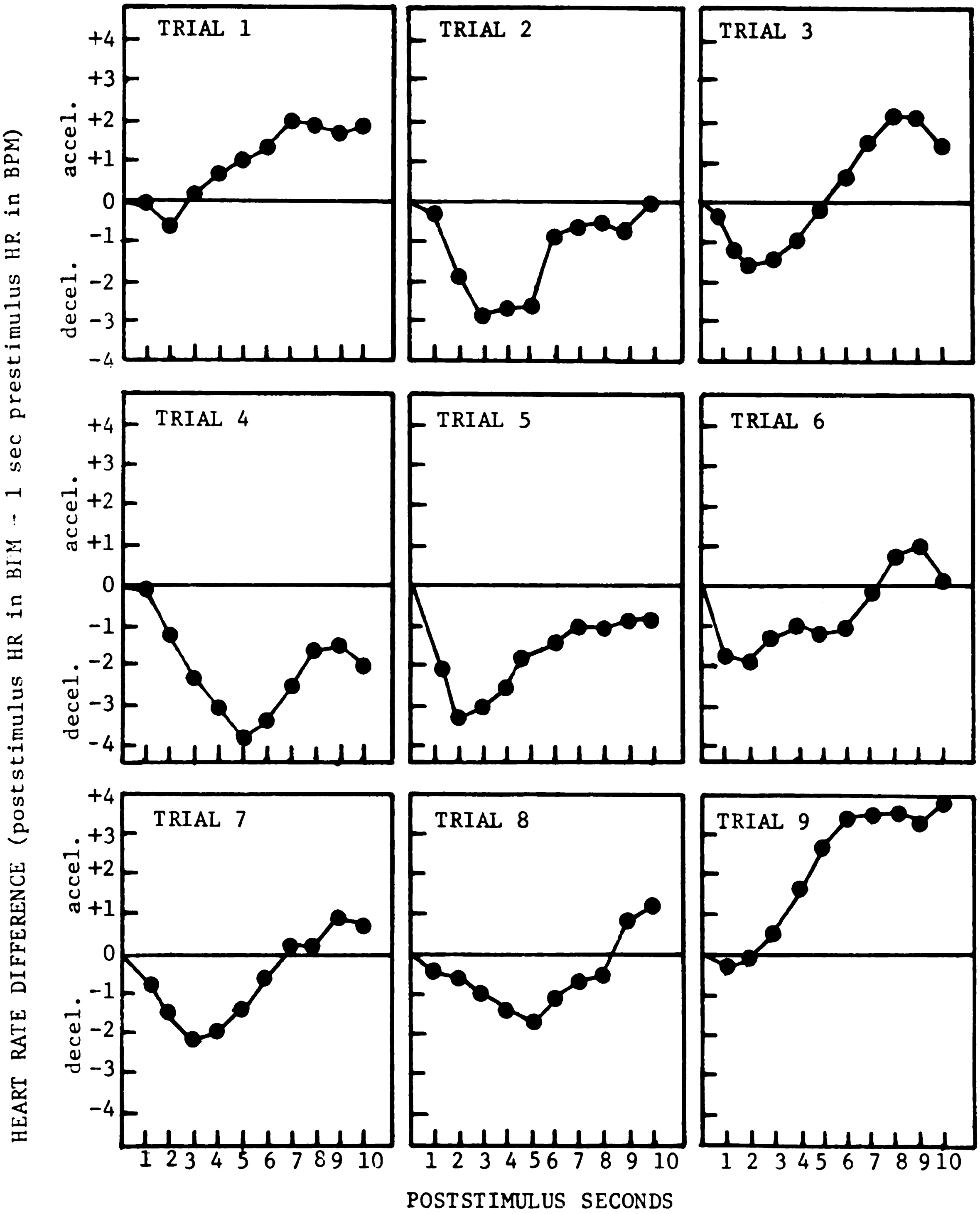


Figure 23. Second-by-second evoked poststimulus heart rate responses on each of the habituation trials (1 through 9), for the Group H infants in Condition B (Transitionless Condition).

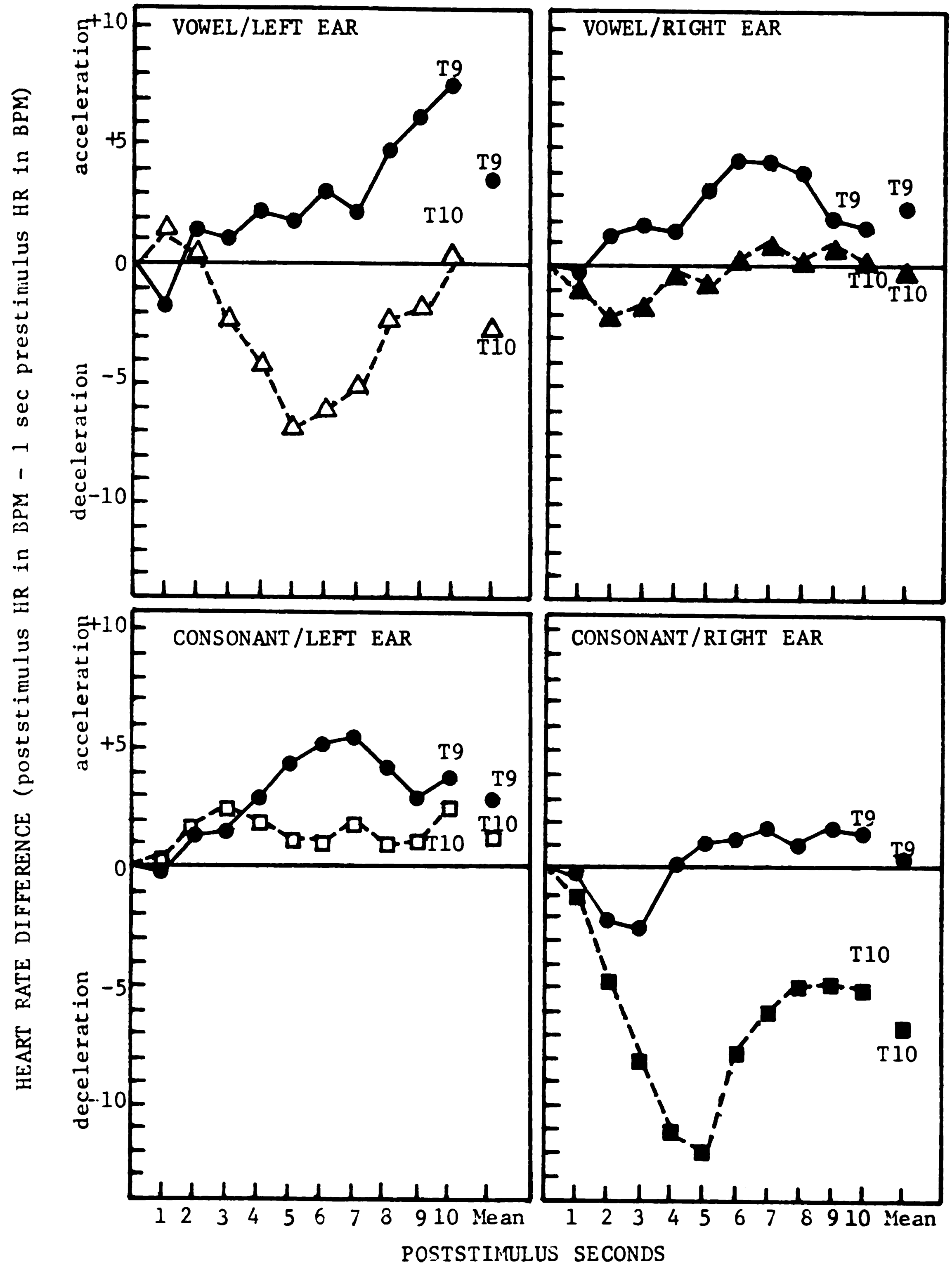


Figure 24. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores, during Left Ear (L) and Right Ear (R) Consonant (C) and Vowel (V) tests, on trials 9 (T9) and 10 (T10), for the Group H infants in Condition B (Transitionless Condition).

Simple effects tests found a significant right ear advantage for the trial 10 cardiac decelerative response to consonant discrimination tests, $F(1, 84) = 7.76$, $p < .01$, but a nonsignificant left ear advantage in the magnitude of trial 10 deceleration for vowel discrimination tests. However, a vowel left ear advantage as well as a consonant right ear advantage are supported by simple effects tests of the trial 9 versus trial 10 Phoneme x Ear effects. Although there were no trial 9 differences in cardiac responses to either ear or either phoneme type, there was significant trial 10 dishabituation relative to trial 9 only for right ear consonant discrimination tests, $F(1, 84) = 7.46$, $p < .01$, and for left ear vowel discrimination tests, $F(1, 84) = 3.88$, $p < .053$, but not for right ear vowel tests or left ear consonant tests. The pre-analysis designation of infants who dishabituated also supports the finding of greater incidence of left ear dishabituation for vowel discrimination tests (10/11 Ss; greater than chance, $Z = 2.717$, $p < .05$) than right ear vowel tests (6/11 Ss; no different from chance, $Z = .302$, $p > .2$), and of greater incidence of dishabituation for right ear (10/11 Ss; greater than chance, $Z = 2.717$, $p < .05$) than left ear consonant tests (3/13 Ss; less than chance, $Z = -2.504$, $p < .05$).

Therefore, the Group H infants in Condition B differed from Condition B adults in several respects. Unlike the adults in the current study, the infants showed a left ear advantage for vowel discrimination, and showed not only a significant general discrimination of the consonant change but also a right ear advantage for consonant discriminations. Both of these infant ear difference findings contrast with some earlier reports of a lack of hemisphere asymmetry in adults for processing of consonants and vowels in CV syllables without formant transitions (e.g., Cutting, 1975; Darwin, 1971), although other studies have reported a right ear advantage for some transitionless consonants (Heymeyer & Sharf, 1975).

To summarize, the Group H infants in both conditions showed cardiac ORs to stimulus presentations, and their cardiac ORs habituated during the first nine trials of all tests. The infants in Condition A (Transitions Condition) showed some evidence of dishabituation on the test trial of all tests, with no ear or phoneme differences in discrimination of the stimulus change. The infants in Condition B (Transitionless Condition), however, showed a strong REA for consonant discrimination, and a weak but significant LEA for vowel discrimination.

An Alternative to Test Trial Dishabituations in Group H Infants

Although it has just been argued that habituation occurred for the Group H infants in both conditions, and that their trial 10 responses reflect the reported patterns of test trial dishabituations, a more conservative possibility exists. It may be that the differences between the Group H infants' trial 9 responses and their trial 10 responses in both conditions are the result of regression effects rather than a reflection of true cardiac dishabituations (Wood, 1977). That is, since the Group H infants were chosen partially for small or no cardiac decelerations on trial 9, the range of responses on trial 9 was artificially restricted toward high responses (cardiac accelerations) and the trial 10 decelerations might be the result of chance or random regression toward the mean.

The author believes that the possibility that statistical regression effects produced the present findings, although valid and worth considering, is less likely than the possibility that the present findings are real and not due to statistical artifact. For one thing, it is accepted practice in research on infant habituation/dishabituation processes to select for the final data set only those infants who show response habituation according to criteria such as those used in the present study. This is true whether subject selection occurs while the data are collected or afterward. Whereas the use of habituation selection criteria in general may bias the data, and lead to the finding of a subsequent response dishabituation or response recovery which actually reflects only statistical regression effects, most of the earlier infant habituation studies have included control groups to assess the contribution of chance fluctuations toward experimental findings. The control groups have had to meet habituation criteria, but have not received a stimulus change after habituation as did the experimental groups. Typically, whereas experimental groups often show response dishabituation, the control groups have failed to show response increases following habituation. This suggests that the experimental group response dishabituations reflect real behavioral processes rather than statistical regression effects.

Although the present investigation did not specifically include a no-stimulus-change control group, it is argued that the results from a large number of studies with various stimuli, which included no-change controls, provide sufficient support that infant habituation/dishabituation effects in general are real, and not due simply to statistical regression. Furthermore, the author argues that the existence and direction of ear differences in Condition B (Transitionless Condition) dishabituations provide further support that the dishabituations reflect actual behavioral processes rather than chance fluctuations, at least in that condition.

In addition, remember that the Group H infants were not chosen simply for high cardiac responses (accelerations) on trial 9. They were chosen for a particular pattern of responses on trials 1 through 9, and for their trial 9 response relative to earlier responses during the habituation trials. Several infants with high trial 9 responses were rejected from Group H analyses because they failed to show low responses (decelerations) earlier in the habituation trials. And on the other hand, several subjects with low trial 9 responses were included in Group H analyses because their trial 9 decelerations, although large, were smaller in magnitude than their earlier decelerations. That is, while the habituation criteria used may bias toward high trial 9 responses, the bias was not strict, was not completely tied to trial 9 responses, and did not directly or completely reduce the variance of responses on trial 9. Moreover, the significant Trials effects in the trials 1 through 9, and the trials 1 and 9, Group H ANOVAs for both conditions further suggest that Group H infants showed a reliable response pattern reflecting habituation throughout the habituation trials, rather than simply showing high trial 9 responses.

Finally, examination of Figures 13 and 14 (test trial results for total sample of infants, both conditions), in comparison with Figures 18 and 24 (test trial results for Group H infants, both conditions), reveals that the selection of infants from the total sample for the Group H analyses did not affect the form or magnitude of any of the test trial cardiac responses. Yet the trial 9 responses do differ for the total sample vs. Group H (understandably). Once again, it seems more likely that the Group H results reflect actual behavioral processes, than that they reflect statistical artifacts. If regression effects were a strong possibility, we would most likely expect the trial 10 responses for Group H to be more substantially different from those for the total sample of infants, as the trial 9 responses differed between the two.

The argument has been presented that the Group H results more likely indicate true behavioral effects than they do statistical artifacts. Of course, this argument is empirically testable. The dichotic infant conditions should be replicated, preferably with appropriate no-change control conditions to directly test for statistical regression. For now, the findings from the Group H ANOVAs are presented as real effects, and the conclusions and speculations regarding infant asymmetries offered in the discussion are based on the assumption that the effects are real. However, the reader has been cautioned that because of the trial 9 biasing effects of the habituation selection criteria used, some possibility exists for statistical regression effects on the trial 10 cardiac responses relative to trial 9.

Summary of all Findings

Habituation of the cardiac OR occurred to repeated dichotic syllable presentations during the habituation trials of all tests (Vowel/Left Ear, Vowel/Right Ear, Consonant/Left Ear, and Consonant/Right Ear) for the adults in Conditions A (Transition Condition) and B (Transitionless Condition), and also occurred for a large subset of infants (Group H) in both conditions. Habituation is interpreted (according to the learning and OR literature) as an indication that these subjects had formed some perceptual or cognitive model of the characteristics of the repeated dichotic syllables. Dishabituation on the dichotic test trials, or recovery of the cardiac OR in response to a change in the phonetic characteristics of one of the dichotic habituation syllables, reflects detection of the mismatch between the novel syllable and the original, habituated syllable it replaced. The pattern of ear differences and phoneme type differences during test trial dishabituations suggests that:

1. adults in both conditions detected the vowel changes, and did so equally well with both ears (cerebral hemispheres);
2. adults in neither condition detected the consonant changes (according to verbal as well as cardiac responses), and this failure involved both ears (hemispheres) equally;
3. approximately half the infants who habituated in each test of Condition A clearly detected the syllable changes, regardless of ear tested or phoneme type, and this resulted in moderate group dishabituation for all tests without ear or phoneme differences in the magnitude of test trial OR recovery;
4. the habituated infants in Condition B detected the vowel change only with the left ear (right hemisphere), and detected the consonant change only with the right ear (left hemisphere).

DISCUSSION

The results for both age groups departed somewhat from major experimental predictions, which were based on previous dichotic findings in adult speech perception. The findings are discussed in light of contemporary research and theory on both speech perception and cerebral asymmetries. It is argued that the difference between these and earlier adult dichotic findings reflects that the adults in this study were not processing the stimuli phonetically. Furthermore, acoustic short term memory differences for consonants and vowels is offered as a basis for the differences in the adults' discrimination of the two phoneme types. Although the possibility is considered that the infants' results indicate specialized phonetic/linguistic processing, the case is presented that they more likely represent infant hemisphere differences in processing certain acoustic features of auditory stimuli. Acoustic short term memory factors may play a role in infant cerebral asymmetries for consonant and vowel acoustic features, as they do for adult consonant and vowel processing, such that the two hemispheres of infants process complementary acoustic properties of auditory stimuli. It is proposed that acoustic-based infant cerebral asymmetries are related to unilateral cortical activation by a subcortical binaural mechanism which responds to the quality and degree of acoustic discrepancy between the dichotic stimuli. Finally, the role of the proposed mechanisms for infant dichotic ear asymmetries in the ontogeny of lateralized perceptual/cognitive behavior is discussed. Since the adults were tested to provide a direct comparison group for the infant subjects, who were the primary focus of the research, the adult findings will be discussed first to serve as a relevant framework for consideration of the infant results.

The Role of Phonetic Processing in Adult Phoneme Discrimination and Hemisphere Asymmetry

Recall that in order to equate the dichotic task as much as possible for the two age groups, adults were instructed only to attend carefully to the syllables in each sequence so that they could hear whether a change in the sounds occurred during the sequence. Habituation/dishabituation research with many stimulus modalities indicates that young infants do attend, or orient, to changes in some parameters of a repeated stimulus, including changes of the sort presented in this study. However, the adults were not told to listen specifically for a phonetic change, and they were not told that the stimuli were dichotic, since the infants could not be instructed about either of those task characteristics.

As pointed out in the introduction, prior dichotic research indicates that most right-handed adults show a left hemisphere advantage for stop and fricative consonant processing (Shankweiler & Studdert-Kennedy, 1967; Studdert-Kennedy, 1970), the degree of which may be diminished if the identification of the consonants presented in the task is not as strongly tied to rapid formant transitions (e.g., /l/, /r/) as it is for the stops and fricatives (e.g., Cutting, 1974b;

Day & Vigorito, 1972). Moreover, the adult left hemisphere consonant advantage can be eliminated by removal of the formant transitions from at least some CV syllables, so that consonant identification can be based only on steady-state consonant noise cues (e.g., Darwin, 1971; but for some possible exceptions, see Heymeyer & Sharf, 1974). On the other hand, under many dichotic test conditions no significant REA has been found in adults for processing isolated vowels, or vowels combined with consonants in nonsense syllables (e.g., Shankweiler & Studdert-Kennedy, 1967; Studdert-Kennedy & Shankweiler, 1970; Darwin, Note 23).

The tasks used in previous dichotic vowel and consonant processing studies nearly always required phonetic identification of the vowels and consonants at some point in stimulus processing. However, phonetic identification was not explicitly required of the adults in the present study, nor was it needed in order to follow the instructions given. The differences in task requirements between this study and former studies may be important to the interpretation of the adult findings. Several measures (e.g., dichotic ear asymmetries, asymmetries in EEG auditory evoked potentials) have revealed shifts in degree and/or direction of hemispheric asymmetries in response to the same verbal stimuli, dependent on whether linguistic or non-linguistic processing was required (e.g., identifying the words or phonemes in a stimulus vs. identifying the intonation contour or the emotional tone--see Bartholomeus, 1974; Haggard & Parkinson, 1971; Matsumiya, Tagliasco, Lombroso & Goodglass, 1972; McKee, Humphrey & McAdam, 1973; Spellacy & Blumstein, 1970; Wood, Goff & Day, 1971; Zurif, 1974).

Under the experimental instructions used in the present study, adults were able to detect vowel changes but were unable to detect consonant changes. Furthermore, they showed no ear asymmetries in discriminating stimulus changes for either phoneme type, regardless of whether formant transitions were present in the syllables. Since the transitionless syllables and those containing formant transitions were easily discriminated and identified by adults in the nondichotic phonetic identification study, we can assume that the adults' failure to detect consonant changes in the dichotic study was not related to poor discriminability or identifiability of the consonants.

A more likely possibility than syllable indistinguishability for the adults' failure to detect the consonant changes can be offered. In order to retain the consonant properties in short term memory and discriminate them under the long ISI habituation/dishabituation conditions used, adults may need to process and identify the consonants phonetically. That the adults did not process the stimuli phonetically is supported by their verbal descriptions of the stimulus changes they heard in the sequences that they thought had included a change. Although most of the adults thought they had heard a change during the vowel discrimination sequences, none of them described it as a change in vowel identity. Their descriptions were basically non-phonetic--a change in loudness, in speaker characteristics, addition of some background noise, or a shift in localization of the stimulus toward one ear. Apparently the non-phonetic listening strategies they were using served adequately for detection of some change in vowel acoustic characteristics, which was not recognized as a phonetic change, but did not serve in general for detection of a consonant acoustic change.[6]

Research and theory about differences between the processing of vowels and consonants suggest some interpretations for the present adult dichotic findings. One of the hypothesized differences is that vowels are relatively unencoded but consonants are highly encoded within the acoustic context. Major theories in speech perception propose that because of their encodedness, phonetic identification of the context-dependent varying acoustic properties of consonants must be accomplished through the engagement of what has been called "speech mode" processing, which is not necessary for the identification of unencoded vowels. Speech mode processing refers to phoneme identification via matching the varying acoustic characteristics of consonants with some abstract codes for mental re-synthesis of the auditory stimulus (Stevens & Klatt, 1974), or with codes for relatively invariant articulatory schemes involved in production of the consonant being processed (e.g., Liberman, 1970, 1972; Mattingly, Liberman, Syrdal & Halwes, 1972).

The present findings may mean that adult consonant discrimination under the short term memory constraints of the paradigm used requires phonetic decoding by a hypothesized left hemisphere speech mode processor (Liberman, 1970). In other words, consonants may not be <u>acoustically</u> discriminable in adult short term memory. Adult short term memory discrimination of consonants may be possible only through comparisons of abstract consonant features identified by the left hemisphere's speech processor. Without some degree of speech processor engagement, short term memory acoustic discriminations among consonants would seem impossible, in light of the adults' failure to discriminate consonants and to show an REA for consonant processing. Vowels, on the other hand, can be discriminated acoustically without reference to the speech processor. That may be why vowel identification in earlier adult studies was accomplished without evidence of hemispheric asymmetry, and why, in the present study, vowel changes could be discriminated without reliance on phonetic processing. Alternatively, however, the differences in adult consonant and vowel discriminations may be attributable to acoustic factors.

Acoustic Short Term Memory Factors in Adult Consonant and Vowel Processing

Consonants and vowels show straightforward acoustic differences, as well as encodedness differences, which may affect the quality of short term memory storage of acoustic information for the two phoneme types. Spoken vowels are relatively long in duration, and consist primarily of steady-state frequency cues that are periodic in nature (the acoustic frequency structure is harmonic, containing only integral multiples of the fundamental frequency or pitch, rather than being acoustic noise composed of all frequencies). In contrast, consonants are brief and typically involve rapid changes in frequency and intensity characteristics, as well as combining acoustic noise and periodicity. The acoustic consonant-vowel differences may be more basic than encodedness differences, and in fact may underlie at least some of the phenomena that have been interpreted as support for encodedness distinctions.

Much evidence suggests that several notable differences in processing consonants and vowels may derive from the effects of their respective acoustic properties on short term memory storage (Pisoni & Lazarus, 1974; Pisoni & Tash, 1974). Simply, the acoustic characteristics of vowels can be easily discriminated, and thus can be directly retained in short term acoustic memory without distortion. The opposite is true for the acoustic characteristics of consonants, which may necessitate phonetic feature coding (here is where the speech processor comes in) for short term memory storage, rather than direct storage of the ephemeral and less discriminable acoustic cues for consonants (e.g., Darwin & Baddeley, 1974; Oden & Massaro, 1978). Various psychophysical techniques (e.g., assessment of the effects of signal/noise ratio on perceptual confusions among vowels and among consonants), and measures of short term memory quality, indicate that there is better short term memory storage of vowel than of consonant acoustic information (Cole, 1973; Crowder, 1971, 1973; Crowder & Morton, 1969; Miller & Nicely, 1955; Wickelgren, 1966; Fujisaki & Kawashima, Note 24). Retention of vowels in acoustic short term memory can be diminished by shortening vowel durations or using acoustically similar vowels such as /i/-/I/ (Darwin & Baddeley, 1974).

Typical findings of categorical perception for consonants but not vowels have been interpreted as support for the notion that consonants depend on speech mode processing and are more highly encoded than vowels. However, it now appears that categorical perception is more clearly related to acoustic short term storage. Consonant perception is categorical simply because consonant acoustic information is poorly stored. As would be expected if consonant-vowel differences in categorical perception are more related to acoustic storage than they are to encodedness, vowel perception becomes more categorical as short term memory storage is made more difficult. For example, vowel perception becomes categorical if vowel durations are greatly shortened

(Pisoni, 1973a, b). Findings of categorical perception for nonspeech sound distinctions which are similar in quality to consonant acoustic distinctions, and therefore likely to show poor acoustic short term storage (e.g., Cutting & Rosner, 1974; Miller, Weir, Pastore, Kelly & Dooling, 1976; Pisoni, 1977), also provide support for the short-term memory basis of consonant-vowel differences.

The fact that an REA for vowel processing can be found under conditions which make acoustic short term storage of vowel information more difficult supports a corollary to the acoustic memory explanation for differences in processing consonants and vowels which is of particular interest to the present discussion. Conditions under which an REA for vowels has been found include brief vowel durations, low signal/noise ratios, and presentations of vowels produced by varying vocal tract sizes (e.g., Darwin, 1971; Haggard, 1971; Weiss & House, 1973). The REA has also been found for some of the same nonspeech sounds which had been found to be categorically perceived (e.g., Cutting, Note 9). It may be that the adults in the present study discriminated vowel changes without phonetic processing, and without hemisphere asymmetry, because of the relative ease of storing vowel acoustic information. In contrast, brief and dynamic consonant acoustic information (particularly for stops and fricatives) may be poorly stored, unless it is somehow coded by left hemisphere mechanisms for categorization. If left hemisphere coding is needed for retention of consonant information, adults' failure to use left hemisphere coding and storage strategies would result in the observed lack of consonant discrimination under the short term memory constraints of the dichotic task used.

Suggestions that the adults failed to detect the consonant changes because they were using nonphonetic processing, and that the failure to detect acoustic (nonphonetic) differences among the consonants arises from poor direct storage of the short-lived acoustic cues, are empirically testable. If nonphonetic processing is a key cause for the discrimination failure, manipulating the instructions to force dichotic phonetic processing should produce detection of the consonant changes under the same presentation conditions, and probably should yield a consonant REA at least for the syllables containing formant transitions. And if auditory short term memory constraints prevent consonant discrimination without phonetic coding under these presentation conditions, because of the brevity and low distinguishability of the consonant acoustic cues, then consonant discrimination without phonetic coding should be improved in the same task by the use of more distinguishable consonants with longer-duration acoustic cues (such as /l/ vs. /m/).

The implication that left hemisphere specialization may be related to brief-duration, hard-to-store, easily confusible acoustic signals is supported by findings that the largest REAs are associated with the briefest, most acoustically similar consonant classes (stops and fricatives). In addition, smaller REAs are associated with longer-duration consonants which are more acoustically dissimilar and are identified partially by steady-state acoustic information (/l/, /r/, /y/--see Cutting, 1974b; Day & Vigorito, 1972). Furthermore, stop consonant perception is particularly difficult for developmental aphasics with left hemisphere involvement, but their perception can be improved by time extension of the stop consonant acoustic cues

(Tallal & Piercy, 1975). We shall consider later the possible relation of the suggested adult left hemisphere specialization for coding and storage of brief, difficult-to-discriminate portions of acoustic signals to the infant ear asymmetry results. But now we shall directly consider the differences between the infant and adult consonant discrimination findings.

Is Infant Consonant Processing Phonetically-based?

The implication that when adults do not use specifically *phonetic* listening strategies, they fail to discriminate consonant *acoustic* characteristics in auditory short term memory, may be very important to the interpretation of the infant findings.

In particular, it is interesting that the infants discriminated the consonant changes while engaging in a task that was at least superficially the same as that in which the adults were apparently unable to discriminate consonant changes (insofar as was possible to control task performance in a similar manner for the two age groups). Furthermore, the infants showed contrasting ear asymmetries for the two phoneme types in the transitionless condition, whereas adults in neither this study nor most previous studies showed ear asymmetries for either phonetic category in transitionless CV syllables.

It might be that the infants showed those phonetic differences from adults in their discrimination and ear asymmetry functions because they naturally tend to engage in specifically linguistic/phonetic processing strategies, rather than using purely auditory processing mechanisms, if presented with speech stimuli. In contrast, adults apparently have to be required explicitly or implicitly by task demands to engage in phonetic strategies. The suggestion that infants automatically engage in phonetic processing when presented speech sounds is in keeping with the general notion that infants process speech "linguistically rather than auditorily." The latter suggestion has been proposed in the conclusions drawn from many studies of infant categorical speech perception (e.g., Eimas, 1974a, b, 1975a, b; Eimas _et al_., 1971; Miller & Morse, 1976; Morse, 1972, 1974). The results of the infant studies suggest that they perceive consonants in a categorical manner, as adults do, even when they are not in some way required to identify the stimuli phonetically.

If the explanation for the present findings and other infant speech perception findings is simply that infants engage in phonetic processing whenever presented with speech, however, we would expect to have found an infant REA for processing or discriminating consonants with noise cues plus formant transitions, since those stimuli were the most similar to natural speech and were also the most "encoded" of the sets of phonemes used. But no consonant REA was found for the syllables containing formant transitions.

To follow the "automatic" phonetic processing model of infant speech perception further, we should expect to find no ear asymmetry for phonetically-based vowel discrimination with or without formant transition cues, for the same reasons adults typically show no ear asymmetry for moderate-length vowels produced under a high signal/noise ratio by a single (albeit artificial) vocal tract. We might even expect a vowel REA from infants, under the reasonable assumption that the infants would recognize vowels as speech but not yet "know" that speech mode processing is unnecessary for vowel discrimination and identification. Again, the observed infant results did not corroborate the most likely predictions based on the "automatic" phonetic processing model of infant speech perception. Although the lack of infant ear asymmetry for discriminating vowel changes in syllables containing formant transitions is consistent with the model, nothing in the model can parsimoniously account for the infant LEA in discriminating vowel changes in transitionless syllables. In addition, adults failed to show a vowel ear asymmetry under the same conditions.

An even more important reason for rejecting the infant phonetic processing model, or at least questioning it seriously, is that it is circular. Quite simply, although it assumes that infants process speech in a different manner from other auditory signals, it fails to account for a means by which infants "know" which signals are speech signals, to be processed in a special phonetic mode. It would seem that some acoustic definition of speech vs. nonspeech is necessary to explain infant speech perception and ear asymmetries.

Acoustic Features and Infant Speech Processing

Given that the model for a specialized mode of phonetic speech processing by infants is neither a final explanation of infant speech processing, nor is it supported by the dichotic data, another suggestion must be offered. A more conservative interpretation of infant speech perception, including the dichotic findings, would be that infants respond to speech sounds on a purely auditory or acoustic basis, rather than processing them phonetically or linguistically. It has already been suggested that infant categorical speech perception may be based on auditory stimulus characteristics rather than on phonetic processing (e.g., Cutting & Eimas, 1975; Studdert-Kennedy, 1974; Sawusch, Note 25).

The suggestion that infants can discriminate speech acoustically rather than phonetically is supported by findings of categorical perception for human speech by other primate species (e.g., Burdick & Miller, 1975; Kuhl & Miller, 1975; Morse & Snowdon, 1975; Waters & Wilson, 1976). It may be that the ear asymmetries found in this and earlier dichotic studies of infants are related to processing of the acoustic characteristics of the stimuli used, and not to a phonetic/nonphonetic processing distinction. The LEA for transitionless vowel discrimination by infants, but not adults, supports the suggestion that infants were processing the stimuli non-phonetically, since an adult LEA for vowel stimuli (including transitionless vowels) has only been found when the stimuli are processed in terms of nonlinguistic rather than phonetic properties (Bartholomeus, 1974; Spellacy & Blumstein, 1970).

If the infants were not engaging in phonetic processing, they were probably responding to some acoustic "trigger features" of the stimuli in order to discriminate among consonants and vowels, and to show ear asymmetries for some of the acoustic properties of vowels and consonants. Innate selective responsiveness of young infants in any species to critical trigger features of the acoustic signals used in intraspecies communication/is biologically adaptive (Marler, 1977; Pisoni, Note 28). A predisposition to respond to acoustic trigger features in human speech/would promote survival of young infants by helping direct their attention to adult caregivers' speech, and thereby aid in the establishment of a reciprocal infant-caregiver bond. Furthermore, it would serve as an initial base for the development of the child's native language, since it would at one and the same time allow receptivity to language experience in general, and also be modifiable by experience with a particular language, through selective perceptual tuning or development of higher-order cognitive strategies such as the assignment of phonetic labels. Possible modification of responsivity to innate trigger features during development may be particularly relevant to the finding that, without phonetic processing, the infants discriminated among consonant acoustic cues, but the adults did not. Perhaps developmental experience serves to reduce the adults' ability to respond directly to purely acoustic trigger features, or to store them directly in auditory short term memory, without the intermediate use of phonetic feature coding.

Acoustic Trigger Features in Infant vs. Adult Speech Processing

One of the current controversies in the speech perception literature is whether the "unique" phenomena in adult phonetic perception, which include categorical perception and dichotic REAs for consonants, can be explained at least in part by auditory neural feature detectors for certain complex acoustic properties of speech (e.g., Cooper, 1974; Cooper & Blumstein, 1974; Cutting, 1974b, 1975; Diehl, 1975; Eimas & Corbit, 1973; Miller, 1975; Uselding & Molfese, Note 26), or whether the phenomena cannot be explained without reference to specialized speech mode processing (e.g., Liberman, 1970, 1972; Liberman *et al.*, 1967; Simon & Studdert-Kennedy, Note 13).

A corollary to the second position is that if acoustic feature detectors are not major determinants of adult speech processing, they cannot be important for infant speech processing either (Simon & Studdert-Kennedy, Note 13; Studdert-Kennedy, Note 27). Although the scope of the present discussion does not include a detailed exploration of the role of acoustic feature detectors in adult speech perception, the argument is advanced that auditory feature detectors can be highly involved in infant speech perception regardless of the role they play for adults.

Trigger feature detection can be invoked as a major speech perception mechanism for infants, even though it may be only a minor mechanism for adults, or perhaps has even become "lost" to direct or conscious use by adults. Indeed, trigger feature detection must be involved in infant speech perception, given the argument that specialized phonetic processing by infants is unlikely. The basis for the different role of trigger feature detection in infant and adult speech perception may be analogous to the basis for some important differences between infant vs. adult motoric reflex behavior. The mechanisms for disappearance of many infant reflexes may serve as a crude model for a proposed loss or diminution by adulthood of reflex-like acoustic trigger feature detection in infants.

Many reflexive properties of the subcortical and spinal levels of the immature nervous system are present in infancy but "lost" by adulthood, for a variety of sensory-motor behaviors in humans and other species. The functional loss of those reflexes occurs as a result of the maturation of more complex, higher-level brain mechanisms, which inhibit the lower-level reflexes. Loss also occurs as a result of the development of complex, higher-order cognitive, perceptual, and motor behaviors which override the simpler reflexive behaviors. For example, consider the adaptive reflexes of early human infancy, such as the tonic neck, Babinski, and Moro reflexes, which drop out as the cortex becomes functionally mature and voluntary motor control develops. Those subcortical and spinal reflexes of infancy can no longer be elicited as reflexes in adults, though some of them may reappear if severe damage to the higher central nervous system destroys cortical inhibition for them (Dekaban, 1959).

The failure to elicit infant sensory-motor reflexes in adults does not imply that the reflexes cannot be important in infant behavioral regulation. Nor does it imply that the reflexes no longer exist in adults. If the reflexes reappear under conditions of nervous system damage, the mechanisms underlying them must have been always present, though inhibited and therefore not directly accessible. For adults, the neural pathways that were involved in infant sensory-motor reflexes are most likely still functional, having become integrated into the pathways associated with more complex, voluntary behaviors. Likewise, acoustic trigger feature detection for speech in adults may still be operational, yet not be observable because its functioning only occurs in the context of more complex information processing for speech signals (e.g., phonetic coding).

A second, perhaps closer analogy can be drawn between developmental changes in cognitive processing and developmental changes in speech signal processing. According to Piaget's model of cognitive development, infants engage in sensorimotor cognitive behaviors, which have been replaced by, or incorporated into, the concrete and formal operational cognitive behaviors of adults. Simply, the infant's processing of world events is derived from feedback from his own movements or actions upon objects and people, or is based on simple organizations of sensory impressions, the latter of which are often related to dynamic rather than static sensory properties. On the other hand, the adult's processing is based on mental representations of complex events, including abstract concepts and symbolic systems such as language. Although isolated sensorimotor processing may at times play a minor role in adults' processing of new information, it has by adulthood been largely subsumed by or integrated into more complex, higher-order cognitive behaviors. Usually the major part of adults' information processing is mediated through language and/or formal logical and concrete logical thinking. Yet the fact that sensorimotor information processing plays a minor and incomplete role in adult cognitive operations does not imply that sensorimotor thinking cannot be important in infant information processing. So far as we know, sensorimotor processing is the only means the infant has to understand and learn about the events around him.

The infant's response to the acoustic features of speech may be at least in part a reflex-like response to (or sensorimotor comprehension of) acoustic trigger features. In line with the explanation of motoric reflex "losses" between infancy and adulthood, the infants' ability, and the adults' inability, to detect acoustic (as opposed to phonetic) changes in consonant sounds in the present dichotic study may reflect the loss or overriding in adults of infant trigger feature responses to consonant acoustic properties, through development of higher central nervous system mechanisms (auditory association cortex, hippocampus, corpus callosum) and/or the development of higher-order information processing strategies such as phonetic coding. The suggestion that infants may possess trigger feature detectors which in adults have become overriden by, or integrated into, higher-order processing mechanisms is supported by some recent speech development findings. Infants make some categorical acoustic speech distinctions which adults in their language environments do not make in either perception or production (e.g., Trehub, 1976). Infant speech discriminations that are not reinforced by their language environment are apparently lost by childhood or adulthood (Pisoni, Note 28). For instance, infants from English-, Kikuyu (Kenya)-, and Spanish-speaking environments show categorical perception for three categories of voicedness (voice onset time, or VOT, distinguishes between /p/ and /b/, for example) among stop consonants: voiced (/b/), voiceless (/p/), and prevoiced. The prevoiced category is not a phonetic distinction in English, Spanish, or Kikuyu, although it is a phonetic category for some languages, such as Thai (Lisker & Abramson, 1964). Although the infants in all three language environments perceive three voicing categories, English- and Spanish-speaking adults perceive only two VOT categories (Lasky, Syrdal – Lasky & Klein, 1975; Pisoni, 1974), and Kikuyu adults perceive only one voicedness category, thus making no stop consonant VOT discriminations (Streeter, 1976).

In some cases, moreover, infants show a slightly different psychophysical category boundary than do the adults in their language environment, which means speech experience must help to shift the psychophysical properties of the boundary. For example, infants in Spanish environments discriminate the stop consonant voiced-voiceless distinction found in English, whereas by adulthood Spanish speakers cannot perceive a category distinction at the English VOT boundary, since in the Spanish language the VOT boundary in speech is shifted about -20 msec from the English boundary (Lasky *et al.*, 1975).

It seems, therefore, that some of the speech perceptual discrimination abilities which infants have are lost by adulthood through lack of exposure to the corresponding phonetic distinctions in the language environment, and some other properties of speech discrimination abilities are lacking in infants but develop through experience by adulthood. The infant speech discrimination abilities just outlined have been suggested to reflect the operation of acoustic trigger feature mechanisms rather than phonetic processing (Cutting & Eimas, 1974; Jusczyk, Rosner, Cutting, Foard & Smith, 1976; Sawusch, Note 25). It may be that there is an infant hemisphere asymmetry in the operation of acoustic trigger feature mechanisms.

Infant Hemispheric Asymmetry for Acoustic Trigger Features, and the Role of Auditory Short Term Memory

The argument has been presented that infants most likely discriminate among speech sounds via (innate) neural responses (and possibly sensorimotor schemata) to acoustic trigger features in phonemes, particularly for consonants. A proposal relevant to the present investigation is that infant dichotic ear asymmetries may derive from an asymmetrical distribution of neural detectors for special acoustic features, especially those in consonants. The question then arises, What are the important trigger features for specialized left and right hemisphere processing in infants? The hypothesis was presented in the introduction that rapid formant transitions are major trigger features for infant left hemisphere processing, based on the results of some dichotic research with adults. The predictions derived from the hypothesis were that an REA would be found only for infants' discrimination of consonant changes in CV syllables containing formant transitions, and that no ear asymmetries would be found for discriminating consonants based on the noise cues in transitionless CVs, nor for discriminating steady-state vowel acoustic information.

The predictions were not upheld, however. The infants as a group showed discrimination of consonants and vowels in CV syllables either with or without formant transitions, yet did not show ear asymmetries for either the consonants or the vowels in the syllables containing transitions. More surprisingly, they showed an LEA for discriminating transitionless vowels, and a large REA for transitionless consonants. The findings imply that formant transitions *per se* are not the major trigger features for infant left hemisphere processing; indeed, the removal of transitions seems to have left other trigger features for both right and left hemisphere processes remaining in the stimuli, and more salient to the infants. Perhaps syllables with consonantal noise cues + formant transitions + steady-state vowel formants combine some trigger features for both right and left hemisphere processing of both consonants and vowels, which may negate any acoustic-based ear asymmetries.

Another way to characterize the acoustic features available to the infants for consonant and vowel discriminations in the various syllables presented, in contrast to the descriptions of noise cues, formant transitions, and vowel formant frequencies, can be offered. Vowels among the CV syllables used in Condition A (Transitions Condition) varied in moderate-duration (about 200 msec), steady-state acoustic characteristics (the vowel formants), which were easily discriminable and easily storable in auditory short term memory. They also varied in brief, dynamic acoustic characteristics (the formant transitions, about 50 msec) which were hard to discriminate and to store. Consonants among the CV syllables used in Condition A varied in brief, steady-state consonant noise cues (about 40-60 msec) which were hard to discriminate and store, and also varied in brief (about 50 msec) dynamic transition cues which were hard to discriminate and store. But the noise and transition cues for consonants in Condition A might sum to provide a moderate-duration (about 100 msec) combination set of acoustic cues which would be easier to discriminate and store. The vowels among the Condition B (Transitionless Condition) CV syllables varied only in moderate duration steady-state cues (the vowel formants) which were easy to discriminate and store. And the consonants among the Condition B CV syllables varied only in brief steady-state acoustic cues (the consonant noise cues) which were hard to discriminate and store. In terms of the stimulus descriptions just listed, the observed infant dichotic findings suggest that in the infant the left hemisphere may be specialized for detecting changes in brief acoustic cues which are difficult to discriminate and store in short term memory, whereas the right hemisphere may be specialized for detecting changes in longer-duration acoustic cues which are easier to discriminate and store. Whether the acoustic cues within these two duration/discriminability/storability categories are steady-state or dynamic may not be important.

The suggested left hemisphere/right hemisphere difference in acoustic discriminations would lead to a left hemisphere advantage for detecting differences among the brief, acoustically similar steady-state consonant noise cues in either the transitionless syllables or in those containing formant transitions, or for detecting differences among the brief, acoustically similar dynamic transition cues for consonants or vowels in the syllables containing formant transitions. And they would produce a right hemisphere advantage for detecting differences among the longer-duration steady-state vowel formant frequencies for vowels in either the transitionless syllables or in those containing transitions. It would follow that discrimination of consonants in transitionless syllables would result in an REA in infants, since the consonant change would be cued only by the brief noise cues. However, discrimination of consonants in the syllables containing formant transitions might be discriminated based either on one of the two types of brief, left-hemisphere-specialized cues (noise or transitions), or on the longer-duration combination of noise + transition cues, which might evoke right hemisphere processing. In balance, either hemisphere might be able to detect the consonant change in the syllables containing formant transitions, so no ear asymmetry would be predicted. Discrimination of vowel changes in transitionless syllables would result in an LEA, on the other hand, since the vowel change would be cued only by longer-duration steady-state vowel formant cues. But no ear asymmetry would be expected for discrimination of vowels in syllables containing transitions, because the vowel difference would be cued both by brief, left-hemisphere-specialized cues (formant transitions) and by longer, right-hemisphere-specialized cues (vowel formants).

This new formulation of the acoustic cues for which the infant's hemispheres may be specialized is consistent with the explanation of adult speech perception based on vowel vs. consonant differences in the quality of short term memory storage. It may be that the left hemisphere specialization in three-month-old infants is tied to a left hemisphere advantage in trigger feature detectors for brief acoustic cues, such as stop consonants, which would be important since fleeting and poorly storable acoustic information would be lost if it neither triggered specialized neural detectors (infants) nor became quickly coded phonetically or semantically (adults). Suggestive support for a hemispheric differentiation in adults between brief/poorly-storable vs. longer/more-easily-storable acoustic properties is provided by several adult speech perception findings. The consonant cues which are briefest, least discriminable, and most difficult to store directly in auditory short term memory, whether steady-state or dynamic, are associated with the largest speech REAs (Cutting, 1974b; Day & Vigorito, 1972; Heymeyer & Sharf, 1974; Shankweiler, 1970; Studdert-Kennedy & Shankweiler, 1970). Furthermore, the REAs found in adults for non-speech stimuli have been associated with brief, difficult-to-discriminate and hard-to-store acoustic cues such as nonphonetic rapid frequency transitions and small differences in rise time for complex acoustic stimuli (e.g., Cutting, 1974a; Halperin, Nachshon & Carmon, 1973; Cutting, Note 9). In addition, adult and child aphasics with left hemisphere dysfunction have their greatest auditory perceptual difficulties with the processing of brief acoustic features which are hard to store and discriminate, whether the signals involved are speech or nonspeech (e.g., Brookshire, 1972; Goldblum & Albert, 1972; Oscar-Berman, Zurif & Blumstein, 1975; Saffran, Marin & Yeni-Komishian, 1976; Tallal & Piercy, 1976). Finally, the acoustic hemisphere asymmetry framework offered in the present discussion can account for earlier speech REAs found in infant cardiac habituation/ dishabituation dichotic studies (Glanville, Best & Levenson, 1977; Best & Glanville, Notes 6 & 7; Glanville, Best & Hoffman, Note 8), since the stop consonant discriminations the infants made among the dichotic syllables presented in those studies were cued only by brief (45 msec) formant transitions and did not contain consonant noise cues (Pisoni, Note 29).

The proposal that infant hemisphere specialization for auditory processing may be based on an acoustic distinction related to ease of direct sensory information storage in auditory short term memory can be empirically tested. If the proposed auditory stimulus class distinction is important in lateralized infant brain function, we would expect to find an infant REA for discriminations among brief, highly similar acoustic characteristics, and an LEA for discriminations among longer-duration, less similar acoustic characteristics, whether the stimuli are consonants or vowels, speech or nonspeech. The music timbre LEA found in previous infant dichotic studies is consistent with this prediction, since the cues for musical timbre discriminations are easily distinguished, easily stored, and approximately the same duration as the steady-state transitionless vowels used in the present study. The relative ease of discrimination and short term storage of the cues for which the right hemisphere is proposed to be specialized may help also to explain why nonspeech LEAs are usually not so strong as speech REAs for both adults and infants (see Glanville, Best & Levenson, 1977; Shankweiler, 1966; Entus, Note 4, p. 94).

Manipulations of the duration of, or ease of direct storage for, critical acoustic cues within the dichotic discrimination stimulus sets should shift ear superiority for auditory discriminations, according to the proposed model. For example, infant consonant REAs should be reduced, or possibly shifted toward an LEA, if consonants with longer-duration, more distinguishable acoustic cues are used in the discrimination sets (e.g., /l/ vs. /zh/), and vowel LEAs even for transitionless syllables should be reduced or possibly reversed in direction if briefer (about 50 msec), less discriminable vowel cues (e.g., whispered /e/ vs. /ə/) are used in the discrimination sets. Moreover, infant REAs should be found for discriminations among brief, difficult-to-discriminate nonspeech auditory characteristics (e.g., the "plucked" vs. "bowed" qualities related to small rise time differences in brief, acoustically complex signals such as clicks--Cutting, Note 9), and infant LEAs should be found for discriminations among longer-duration, acoustically dissimilar nonspeech (e.g., animal calls) or speech sounds (e.g., intonation contour differences in long vowels). The proposed acoustic dichotomy may allow the two hemispheres to perform complementary functions in auditory processing.

Infant Hemispheric Complementarity in Acoustic Functions, and the Development of Lateralized Brain-behavior Relations

Hemispheric asymmetry for the two acoustic classes just described may be seen as a specific example of some more general characterizations of the functional differences between the two hemispheres. The general characterizations of the left hemisphere vs. right hemisphere processes, respectively, have included: analytic vs. holistic (Bever, 1975; Bever & Chiarello, 1974; Levy-Agresti & Sperry, 1968), sequential- vs. parallel-processing (Carmon & Nachshon, 1971; Cohen, 1973; Natale, 1977; Papcun, Krashen, Terbeck, Remington & Harshman, 1974; Robinson & Solomon, 1974), focally- vs. diffusely-organized (Semmes, 1969), stimulus-match-detecting vs. stimulus-mismatch-detecting (Tomlinson-Keasey, Kelly & Burton, 1978). Several similarities can be found among these proposed hemispheric dichotomies, but one of the most striking is their underlying implication that left hemisphere specialization involves fine-grain processing of, and sequential memory for, similar stimuli, whereas right hemisphere specialization involves comparisons of gestalt perceptions, or recognition of interstimulus differences in intrastimulus organizations, among more dissimilar stimuli. The present hypothesis regarding infant left hemisphere and right hemisphere specialization for discriminations among brief, similar vs. longer, more dissimilar acoustic characteristics, respectively, fits the more general hemispheric dichotomies. Furthermore, the general characterizations of hemispheric asymmetries all imply that complementarity of functions may be of great importance to humans (Crinella, Beck & Robinson, 1971; Teuber, 1974).

Several recent investigations with split-brain individuals (those who have had their corpus callosa surgically severed for intractable epilepsy, cutting off interhemispheric communication at the cortical level), support the suggestion that the hemispheres perform complementary functions. The complementarity of hemisphere functions in split-brain subjects is an obvious advantage to those individuals, and the separation of functions as a result of the surgery indicates that at least in adults the complementary functions are integrated largely through the corpus callosum (e.g., Gazzaniga, 1977; Levy & Trevarthen, 1978; Springer & Gazzaniga, 1975).

Reports of persistent selective intellectual deficits in individuals with early unilateral cortical damage correspond well in quality (but may be smaller in degree) with general hemispheric asymmetries found in normal and brain-damaged adults, and also provide support for the adaptive role of complementary hemispheric functions for the development of the individual (e.g., Aicardi, Amsili & Chevrie, 1969; Alajouanine & Lhermitte, 1965; Annett, 1973; Annett, Lee & Ounsted, 1961; Byers & McLean, 1962; Dennis & Kohn, 1975; Dennis & Whitaker, 1976; Dunsdon, 1952; Hécaen, 1976; Kohn & Dennis, 1974; McFie, 1961; McFie & Thompson, 1971; Rudel & Teuber, 1974; Smith, 1976; Taylor, 1883; Teuber, 1970; Woods & Teuber, Note 30). The adaptive advantage of hemispheric complementarity is apparently so strong that children with unilateral left brain damage quite often retain, or develop, left hemisphere language specialization, unless there is extensive damage to the specific speech areas (Milner, 1974; Rasmussen & Milner, 1977). Moreover, it has been convincingly argued that complementary functional organization of the cerebral hemispheres has provided an adaptive advantage in the evolution of the human species as well as for the individual species members (Levy, 1969, 1974, 1977; Teuber, 1974).

The proposed infant hemisphere dichotomy between two classes of acoustic characteristics may serve as a basis for the development of hemispheric complementarity in higher-order cognitive and perceptual functions such as those found in adults. An acoustic processing distinction like the one offered here would allow for the complementary processing of different acoustic properties of auditory speech and nonspeech stimuli. It may be that different neural organizations for separate processing and means of short term storage for the two stimulus classes is more efficient in some way than a single neural organization to handle both acoustic classes would be. The complementarity in processing may allow for faster and more complete integration of important information about the two types of acoustic information in a given auditory signal.

Differences between infants and adults in ear asymmetries for auditory discriminations might result from increasing hemispheric integration as a function of neural maturation and development of more complex information processing strategies. The shift from an infant LEA for discriminating transitionless long-duration vowels to a lack of adult ear asymmetry for the same task may reflect in part the effects of those developmental changes on functional hemispheric asymmetries, as suggested by the earlier discussion of possible general changes in trigger feature responses. Experience with language processing, and the development of phonetic, semantic and syntactic strategies, may override the infant's stimulus-property-related LEA for steady-state vowels, leading to a loss of steady-state vowel LEA by adulthood. In addition, functional maturation of the corpus callosum, auditory association cortex, and hippocampus during and after infancy may allow for increasing amounts of inter- and intra-hemispheric integration in auditory stimulus processing, and thus could contribute to the ontogenetic changes found in degree and direction of lateralization for consonant and vowel discrimination.

Several investigators have suggested that the infant is functionally split-brain until around two or so years of age, and thus shows a low degree of interhemispheric influence and integration (Gazzaniga, 1970; Molfese, Freeman & Palermo, 1975), based on evidence that the human corpus callosum is incompletely myelinated until perhaps years after birth (Hewitt, 1962; Selnes, 1974). It has been suggested that infants may show some amount of callosal function (Entus, Note 4), since complete myelinization is not necessary for the functioning of immature nervous system structures (Prechtl, 1971; Robinson, 1969). However, age changes in latency and amplitude of interhemispheric transfer for unilaterally produced sensory evoked potentials suggests that the infant's corpus callosum does show slower and weaker interhemispheric sensory information transfer than that of the older child or adult (Salamy, 1978). The differences between infants and adults in discrimination and direction of lateralization for vowels and consonants may be related in part to functional development of the corpus callosum, which would allow more mutual influence between the hemispheres of older subjects for processing the two acoustic stimulus classes. One suggestion for the role of the corpus callosum in hemispheric interactions is that it serves as a medium for mutual functional inhibition between the two hemispheres, leading to an ontogenetic increase in functional lateralization (e.g., Bryden & Zurif, 1970; Gazzaniga, 1970, 1972; Gazzaniga & Hillyard, 1973; Molfese, Freeman & Palermo, 1975; Entus, Note 4). However, mutual hemispheric inhibition may not be the only, or even the primary, function of the corpus callosum related to brain lateralization (cf., Fowler, 1975).

Infant Acoustic Hemispheric Complementarity and a Possible Mechanism for Acoustically-based Unilateral Hemisphere Activation

Hemispheric functional complementarity for infants' processing of acoustic features, dependent on duration and ease of short term memory storage, seems to account parsimoniously for the infant ear asymmetry findings in this and earlier dichotic studies of infants. It also provides a simple description of the acoustic cues by which infants can perceptually dichotomize the general classes of speech and nonspeech sounds. Running speech contains many brief, acoustically similar cues that are important for segmentation and processing, whereas such cues are relatively unimportant for comprehension of many non-speech sounds. The proposed acoustic dichotomy may thus answer the question of how infants may "define" an auditory stimulus as speech, which was left unanswered by the specialized phonetic processing model. Yet there remains a riddle that the acoustically-based functional asymmetry described so far cannot solve--Why do only half the infants in Condition A (Transitions Condition) dishabituate to the stimulus change in each of the four test sequences (Vowel/Right Ear, Vowel/Left

Ear, Consonant/Right Ear, Consonant/Left Ear)? According to the acoustic asymmetry model, we would expect all, or nearly all, of the infants in each test sequence to detect the changes, since in each case the change should be discriminable by either right-hemisphere-specialized or left-hemisphere-specialized acoustic cues. But the vowel and consonant changes in the syllables containing transitions seem to have been undetected by half the infants, regardless of which ear received the novel test stimulus after the habituation trials. The picture of infant cerebral asymmetry mechanisms looks a bit more complicated than the simple acoustic dichotomy model can account for.

Consider that in each of those four test sequences the individual infants might have been showing unilateral hemisphere activation, rather than equal activation of the two hemispheres. Thus they may have been responding either with greater left hemisphere activity to the brief formant transition cues for consonants or vowels (or brief consonant noise cues), <u>or</u> with greater right hemisphere activity to the longer steady-state vowels or the summed noise + transition cues for the consonants. Since both types of cues were available in all the syllables containing transitions, it might be reasonable to expect that by chance about half the infants would have shown left hemisphere activation for brief cues, and half would have shown right hemisphere activation for longer cues. It would follow that in each test sequence only the half of the infants with predominant activation of the hemisphere contralateral to the ear tested would hear the stimulus change, given that dichotic competition nearly completely suppresses ipsilateral ear-to-brain transfer and allows primarily contralateral transfer. Basically, the infants would hear the change only if asymmetrical hemisphere activation focused attention to the ear receiving the change. Because the stimulus characteristics available would allow for either left hemisphere activation or right hemisphere activation, we would expect about half the infants in each test to be attending to the ear receiving the stimulus change.

The syllable changes in Condition B (Transitionless Condition), however, were cued only by brief acoustic properties (consonants) or only by longer-duration properties (vowels), and in no case were cued by both properties. Therefore, in Condition B we would expect nearly all of the infants in the vowel test sequences to be attending to, and thus to detect the change with, the left ear. Conversely, we would expect nearly all of the infants in the consonant test sequences to be attending to the right ear. The pattern of results just predicted, based on critical acoustic cues, corresponds very well with the pattern actually observed (with the exception that about half the infants in the Condition B vowel test sequences also heard the right ear vowel change--but recall the earlier argument that LEAs are usually smaller than REAs because the discriminations are easier).

Unilateral hemispheric activation in infants in response to certain acoustic properties of auditory stimuli thus may help account for the patterns of test trial dishabituations found in individual infants tested under the two stimulus conditions. But what could underlie unilateral hemisphere activation in infants? Theories about attentional mechanisms for functional hemisphere asymmetry in adults (e.g., Fowler, 1975), and for the development of hemispheric asymmetry, suggest the likely possibility that some lateralized attention-directing strategy may cause unilateral hemisphere activation dependent on task demands. In the present dichotic study of infants, the task of discriminating stimulus changes might lead to unilateral hemispheric attention-focusing dependent on critical acoustic properties of the syllables presented.

Results from studies of the effects of attentional strategies on ear asymmetry for verbal stimuli have been inconsistent regarding the hypothesis that the adult and child REA for verbal stimuli is explained by unilateral left hemisphere attentional strategies which increase right ear performance. Some studies provide support for the attentional bias hypothesis (e.g., Haydon & Spellacy, 1973; Oxbury, Oxbury & Gardner, 1967; Spellacy, 1969; Treisman & Geffen, 1968; Treisman & Riley, 1969), while others fail to support it (e.g., Inglis & Sykes, 1967; Porter & Berlin, 1975; Myers, 1970). But those attentional bias studies often assessed the effects of voluntary strategies for unilateral direction of attention. If an attentional bias underlies cerebral asymmetry, or at least some aspects of asymmetry, the bias more likely is not completely under direct voluntary control (Kinsbourne, 1970, 1973, 1974), but can be assessed primarily indirectly through manipulations of task demands (Hiscock & Kinsbourne, 1977; Curcio, Note 2; Hiscock, Note 3). In the case of the infants, the direction of the attentional bias would be determined by the task demands imposed by the critical acoustic features involved in the novel stimulus change--whether they were brief and hard to discriminate or longer-duration and easier to discriminate.

Several details regarding the operation of an attention-biasing mechanism in infant cerebral asymmetry are yet unclear. One important question left open is, What would cause the mechanism to respond to those particular properties of the dichotic habituation stimulus which would later be important for the detection of the stimulus change on the test trial? Since the habituation pair always differed only in the critical phoneme (vowel or consonant) to be discriminated on the test trial, a response to the discrepant portions of the habituation syllables would focus the attentional mechanism on the particular acoustic feature(s) which would later change in the novel test syllable. Non-discrepant portions of the habituation pair would not affect the attention-directing mechanism, so that the acoustic properties of the discrepant portions of the dichotic syllables would cause the mechanism to activate the appropriate hemisphere.

Perhaps the degree of acoustic discrepancy for the habituation pair, in terms of both the duration and the overall spectral characteristics of the discrepant portions, would serve as the cue for the direction of unilateral hemisphere activation. A small degree of dichotic acoustic discrepancy would lead to left hemisphere activation, and a large degree of discrepancy would lead to right hemisphere activation. Moderate degrees of discrepancy would be ambiguous regarding left hemisphere or right hemisphere activation, and thus would lead either to equal activation of both hemispheres, or to an equal probability of activation for either hemisphere. Based on habituation pair vs. novel syllable discrepancies for consonant and vowel tests in both conditions (Transitions and Transitionless), we would expect preferential left hemisphere activation for transitionless consonant tests, and preferential right hemisphere activation for transitionless vowel tests. This could produce the observed vowel LEA and consonant REA in infants.

For the syllables containing formant transitions, equal probability activation of either hemisphere would be expected if the attentional mechanism focused either on the brief, similar portions of the acoustic discrepancy between the habituation syllables, <u>or</u> on the longer-duration, less similar portions of the discrepancy. Thus, in Condition B (Transitionless Condition), vowel and consonant discrimination would be expected for half the infants in each of the tests, regardless of ear tested. That is, in each test, half the infants would be attending to the left ear and half to the right ear.

Studies of adult dichotic fusion, or the tendency to combine inputs from the two ears to "hear" a single stimulus (Cutting, 1975, 1976; Cutting & Day, 1972, 1975), offer suggestive support for the idea that at some point in dichotic processing the amount of acoustic discrepancy between the ears is somehow noted (not necessarily consciously). Dichotic fusion of stimulus characteristics for discrepant signals to the two ears is very likely under the typical dichotic test presentation condition of simultaneous stimulus onsets for the two ears (e.g., Kirstein, 1973; Kirstein & Studdert-Kennedy, Note 31), which was used in the present study. Dichotic fusion is also most likely for acoustically similar portions of stimuli with the same fundamental frequency (F_0-- the stimuli used in this study had the same F_0), such that stop consonant or fricative consonant noise cues tend to fuse because of their high acoustic similarity. However, formant transitions fuse partially, and vowels tend not to fuse, because of their respective moderate and low acoustic similarity or degree of frequency overlap (Repp, 1976a, b; Halwes, Notes 32 & 33; Repp, Note 34). Also, neither musical notes played by different instruments, nor musical chords, will fuse because of their durations and acoustic dissimilarity (Yund & Efron, 1976).

The conditions under which dichotic fusion occurs correspond well with the role of vowel and consonant acoustic differences in adult speech perception phenomena and also with the proposed infant hemisphere asymmetry for the two basic categories of acoustic features. It may be that dichotic fusion occurs for infants under similar conditions as it does for adults--that is, brief, acoustically similar cues will be highly fused and will produce an REA, whereas longer, acoustically more dissimilar acoustic cues will not fuse and will lead to an LEA (or perhaps to no ear asymmetry, if they are very dissimilar and thus easy to discriminate). In light of this discussion, it may be of particular interest that suppression of ipsilateral ear-to-brain transmission is greatest for very brief sounds (Darwin, 1974).

At What Processing Level Does Dichotic Fusion Occur?

One hypothesis that has been offered about adult dichotic fusion is that it occurs at a high level of stimulus processing, after ear information has reached the two cerebral hemispheres (Repp, 1975). However, it seems more likely that dichotic fusion arises from direct comparison of information from the two ears, at a subcortical level prior to hemispheric and phonetic processing (Pisoni & McNabb, 1974). The latter suggestion is supported by evidence that dichotic speech masking or interference, another indication of dichotic fusion, is most likely when the masking stimulus in one ear is acoustically very similar to the speech stimulus to be detected in the other ear. Dichotic masking of a vowel by another vowel is very unlikely. But dichotic masking of consonant cues by other similar consonants, or by broadband nonphonetic frequency transitions, or by frequency-limited noise bursts, is highly likely. The masking results indicate that the dichotic interference occurs at the level of signal integration from the two ears, prior to hemispheric or phonetic processing. Moreover, as the degree of dichotic masking increases, so does the REA for the masked stimulus (Berlin, 1977).

There is clinical evidence from the effects of subcortical damage on dichotic fusions and REAs that dichotic integration occurs at the level of higher brainstem structures such as midbrain and thalamus (Berlin, 1977). Although much emphasis has always been placed on the near-exclusive role of the cortical hemispheres in speech processing and functional brain asymmetries, the functioning of higher brainstem structures has also been found important in adult speech perception (e.g., Riklan & Levita, 1969). The brainstem structures may also play an important role in infant speech perception. An anencephalic infant between 3-6 weeks of age showed categorical perception for stop consonants under stimulus presentations at long intertrial intervals, although the infant had no functional brain development above the midbrain (Graham, Leavitt & Strock, 1978).

Binaural integration, including auditory localization, is a major function of brainstem auditory centers (Evans, 1974). That brainstem functions seem important in dichotic fusion phenomena (and play some role in general speech perception) suggests that the binaural integration mechanisms used in auditory localization may also be involved in hemispheric asymmetry for dichotic tasks. Several studies indicate that auditory localization mechanisms indeed affect hemispheric asymmetry by introducing lateral attentional biases during the processing of discrepant auditory stimuli presented from two laterally placed loudspeakers rather than over stereo headphones. The lateral loudspeaker set-up produces an LEA for musical tone sequences (Deutsch, 1975) and an REA for speech sounds (Morais, 1975; Morais & Bertelson, 1973). In other words, it seems likely that at least for adults, subcortical auditory localization mechanisms may serve to unilaterally focus attention or activate either cerebral hemisphere, dependent on the amount of binaural fusion of the acoustic signals from the receptive fields for the two ears. Ear asymmetries are not necessarily dependent on strictly dichotic presentations.

A lateralized attention-directing subcortical localization mechanism related to the degree of binaural acoustic fusion may also explain the infant dichotic listening results. Physiological and behavioral findings indicate that the mechanisms for binaural integration and auditory localization are functionally mature very early in infancy, and certainly are evident by 3-4 months, the age of the subjects tested in the present study. The human auditory central nervous system is structurally and functionally mature at birth, up to at least the level of the inferior colliculus (midbrain--see Hecox, 1975). Even during the neonatal period infants will show signs of auditory localization in lateralized behavioral orienting to sounds (e.g., Moreau, Birch & Turkewitz, 1970), especially in response to the human voice, for which rightward turning is stronger than leftward (e.g., Alégria & Noirot, Note 35), suggesting greater left hemisphere

activation. By 3-4 months of age, infants show evidence of other more complex types of auditory localization, including the use of integrated binaural cues to associate a particular sound with a particular visual stimulus object (Lyons-Ruth, 1977) and to detect mother's voice against a background babble of voices (Benson, Note 36). Thus it would seem that 3-4 month-olds have considerable ability to integrate binaural signal information for complex behavioral processes involving auditory localization. It should be possible that binaural integration similar to that involved in auditory localization causes unilateral direction of attention in infants this age, in turn leading to left hemisphere or right hemisphere activation dependent on the degree of dichotic acoustic fusion.

Several experiments can be suggested for testing aspects of the proposed role of an attention-directing mechanism, which produces unilateral cortical activation based on the degree of dichotic stimulus discrepancy, in infant dichotic listening. If unilateral cortical activation during dichotic presentations focuses attention on the contralateral ear, which in turn allows for detection of stimulus changes only by that ear (except for big changes), then measures of unilateral cortical activation (e.g., auditory evoked response asymmetries over the two hemispheres, lateral eye movements, head turns) during a dichotic habituation/dishabituation test like that used in the present study should predict whether the infant will detect the stimulus change by a given ear. Manipulations of the acoustic similarity between dichotic habituation stimulus pairs in a habituation/dishabituation test should shift direction and/or degree of ear asymmetries dependent on the amount of binaural fusion which would occur, regardless of the general stimulus classes used (i.e., speech, nonspeech, consonants, vowels). For example, reducing the degree of consonant fusion by making the fundamental frequencies discrepant for the two dichotic syllables should reduce the consonant REA, as should the use of highly dissimilar, relatively long-duration consonants.

Conversely, increasing vowel binaural fusion by using whispered vowels or brief, highly similar vowels should decrease the transitionless vowel LEA or perhaps cause a shift to vowel REAs. Similar dichotic LEA and REA effects should be found for nonspeech stimuli, dependent on the amount of binaural fusion. Furthermore, if the amount of fusion in the dichotic habituation stimuli causes a unilateral direction of attention, it should be possible to produce left hemisphere or right hemisphere activation by manipulation of dichotic acoustic discrepancies for the habituation pair. It should then be possible to predict whether dishabituation will occur for a given test stimulus in a given ear, dependent on the hemisphere activated and the type of acoustic change present in the novel stimulus relative to the habituation stimulus. For instance, according to the proposed model, a dichotic habituation stimulus composed of vowel-discrepant transitionless syllables should cause right hemisphere activation. If the novel stimulus presented on the test trial is vowel-discrepant from the habituation pair, but contains formant transitions, a vowel LEA should be found because of right hemisphere activation by the habituation pair, although no ear asymmetry was found for a transition vowel change when the vowel-discrepant habituation stimuli contained formant transitions. On the other hand, a vowel REA for the same novel syllable should be found after habituation to a consonant-discrepant transitionless syllable pair, since that habituation stimulus in that case should have produced left hemisphere activation.

The Role of Unilateral Cortical Activation In the Development of Lateralized Perceptual/Cognitive Behavior

A final speculation is offered about the possible role of a subcortical attention-directing mechanism, which unilaterally activates either cerebral hemisphere dependent on critical acoustic cues in auditory signals, for the development of functional lateralization of the cerebral hemispheres. It is suggested that the attention-directing device may serve to provide each hemisphere with a restricted set of sensory experiences during a sensitive period of early childhood development, the quality of which would be defined by the stimulus characteristics that determine the direction of cortical activation. The proposed complementary sets of restricted inputs would selectively modify the neural properties and organization of the two hemispheres during the sensitive period (although some degree of cortical asymmetry in functional neural properties and organization may also be present at or before birth), which in turn would cause the two hemispheres to serve as increasingly asymmetrical substrates for the further development of asymmetries in higher-order perceptual and cognitive functions.

There is much evidence from studies of other species that selective experience in early development modifies the selective responses of cortical feature-detecting neurons for complex stimuli in the visual modality (e.g., Blakemore, 1974; Blakemore & Mitchell, 1973; Pettigrew & Freeman, 1973; Pettigrew & Garey, 1974; Pettigrew, Olson & Hirsch, 1973), as well as in the auditory modality (e.g., Clopton & Winfield, 1976). Connections among cortical neurons are also greatly increased during the early developmental sensitive period by exposure to visual stimuli (e.g., Coleman & Reisen, 1968; Cragg, 1972; Garey, 1974) and auditory stimuli (e.g., Fehér, Ferenc & Halász, 1972). The selective modification of neural responses by restricted sensory experience during the sensitive period is paralleled by behavioral deficits in pattern discrimination and recognition that are directly related to the type of visual restriction (e.g., Ganz, Hirsch & Thieman, 1972) and auditory restriction (e.g., Patchett, 1977; Tees, 1967a, b) for animals, as well as for human visual restrictions (e.g., Freeman & Thibos, 1973) and speech-related auditory restrictions (e.g., Lasky _et al_., 1975; Streeter, 1976).

Greater functional plasticity both for the attention-directing mechanism, and for the neural properties of the two cortices, during early development than during adulthood may allow for greater possibilities in functional/structural reorganization following early central nervous system damage relative to later damage. It may be because of these developmental changes in plasticity for functional reorganization of the unilateral attention-directing mechanism, and of hemispheric functional properties, that early brain-damaged individuals show less severe cognitive and behavioral deficits than individuals suffering an equal extent of damage after adulthood (e.g., Dennis & Kohn, 1975; Kohn & Dennis, 1974; Smith, Note 37; vs. Milner, 1969; Teuber, 1962). Developmental plasticity changes may also explain why corpus callosum sectioning in adults produces more clearly separated functions for the two hemipsheres (e.g., Gazzaniga & Hillyard, 1973; Sparks & Geschwind, 1968; Zaidel, Notes 38, 39, 40 & 41), than that found for some cases of callosal agenesis (e.g., Bryden & Zurif, 1970).

The model also suggests the possibility that certain abnormal developmental states of cerebral dominance, such as a nonsignificant REA for speech stimuli in language-disordered children (e.g., Sommers & Taylor, 1972), may be related more directly to unilateral attention-focusing deficits than to a lack of hemispheric processing specialization *per se* (although defective attention-direction should consequently also affect the asymmetrical functional development of the two hemispheres). Also, evidence for right hemisphere language specialization in a child who was deprived of language input until adolescence, and then began to develop language, suggests that lack of relevant experience during a language-sensitive period (severe left hemisphere deprivation) may have allowed the left hemisphere to organize in a manner that does not support language (Krashen, 1973). It may be that the child's right hemisphere received enough stimulation to show some appropriate functional development. The language this deprived child began to develop may have characteristic properties of right hemisphere processing, like the language found in Dennis and Kohn's (1975) early right hemiplegics (left hemisphere loss in infancy), rather than having the characteristic properties of normal children's left hemisphere language development.

Summary of Conclusions

It was proposed that the adults in this study discriminated vowels but not consonants because they did not engage in phonetic processing during the dichotic tests. Since short term memory storage for vowel acoustic information is much more efficient and direct than storage of consonant acoustic information, adults could discriminate the vowel changes nonphonetically, but could not discriminate the consonants. The adults failed to show a consonant or vowel REA apparently because they did not engage left hemisphere phonetic coding processes in either discrimination.

The sum of the infant findings suggests left hemisphere specialization for discriminating among brief, acoustically similar auditory characteristics, and right hemisphere specialization for discriminating among longer-duration, more dissimilar auditory characteristics. The possibility of a left hemisphere specialized phonetic processing mechanism in infants was rejected for lack of unequivocal support. A subcortical attention-directing mechanism was proposed, which produces unilateral hemispheric attentional activation dependent on the degree of acoustic discrepancy between the members of dichotic stimulus pairs. Unilateral hemisphere activation would focus attention on the contralateral ear, leading to discrimination of a stimulus change only (or primarily) by that ear. The attention-directing mechanism would activate the left hemisphere when a dichotic stimulus pair is discrepant only for brief, acoustically-similar characteristics, and would activate the right hemisphere when the dichotic stimuli are discrepant only for longer-duration, more acoustically-dissimilar characteristics. Dichotic stimuli that differ in both acoustic properties may lead to an equal probability of activation for either hemisphere.

FOOTNOTES

FOOTNOTES

[1] Since there is evidence for stronger and more consistent cerebral lateralization in right-handers than left-handers (e.g., Branch, Milner & Rasmussen, 1964; Goodglass & Quadfasel, 1954; Herron, 1978), and there is still controversy over whether the genetics of handedness affect the degree and direction of cerebral asymmetries significantly (e.g., Bryden, 1975; Levy & Hemmes, 1977; Levy & Nagylaki, 1972), data on familial writing handedness were collected. Both parents of the infant subjects were right-handed, except in five cases (two males and three females). In those five cases, only one of the parents was reported to be left-handed. The test results for these five subjects were not noticeably different from the results for infants whose parents were both right-handed, so no separate analyses were run dependent on parental handedness for the infants in the final data set.

[2] The letters were sent when the infant was about 2 1/2 months old. One version of the letter included a stamped, self-addressed postcard for the parents to fill out and return if willing to bring their baby in to participate in the study. Those who responded were then contacted by telephone to arrange a time for testing, and to provide an opportunity for them to ask questions about the study. At the onset of the study, this was the only recruitment method used, but later a second slightly different recruitment method was added, because this original method yielded a low response rate (40/386, or 10.16%). The second method consisted of sending a letter essentially identical to the original letter, except that the parents were told that they would be contacted by telephone regarding participation, rather than asked to return a postcard. This second method yielded a higher positive response rate (43/101, or 42.57%), and was used after the second month of the study for those parents listed in the telephone directory. The parents of the experimental subjects were fairly young (mother: M_{age} = 26.38 years, SD = 3.65, range = 20-34; father: M_{age} = 27.32 years, SD = 3.31, range = 21-35), well-educated (mother: M_{educ} = 14.61 years, SD = 2.36, range = 11-20, 75 percent had some college; father: M_{educ} = 15.18 years, SD = 2.78, range = 11-20+, 71.4 percent had some college), and the fathers had lower-middle to upper-middle class occupations (except for four graduate students). About one-third of the mothers were employed at the time of the study (11/28), nearly all of whom held professional (middle class) positions (9/11).

[3] The general procedure for the infants in Conditions A and B was essentially the same. The only difference between the two conditions was the difference between the two stimulus sets described in the text.

[4] Possible scores on the questionnaire ranged from 13 points for a "strong right-hand preference" on all items to 65 points for a "strong left-hand preference" on all items. Mean score for female subjects was 18.8 (S.D. = 3.94, range = 13-26), and mean score for males was 18.4 (S.D. = 4.13, range = 13-26). Two female and three male subjects had one left-handed parent, although they were themselves strongly right-handed. The test results for these subjects did not differ noticeably from the results of subjects with two right-handed parents.

[5] The following programs, developed in laboratory, were used: THRSHCHK for checking the trigger level of the computer for ECG R-waves in heart period scoring, R-TIMER for heart period scoring, HRDEDIT2 for editing trigger errors in the heart period data obtained through R-TIMER, and BPM-12 for transforming the heart period data from R-TIMER to weighted average heart rate/sec.

[6] The cardiac ORs shown by the adults in the dichotic study, including the vowel dishabituation ORs, were very small in magnitude, although the form of the deceleratory responses was statistically significant and there were significant differences among trials in absolute magnitude of the responses. The discussion about the possible role of phonetic processing in consonant discrimination under the constraints of the present habituation/dishabituation paradigm may provide a clue to the small OR magnitude, when considered within the context of a recent reformulation of the neuronal model concept of the orienting response (Velden, 1978). The author of that model argues convincingly that in order to account for the observed strength of an orientation reaction, it is necessary to view the information content of a stimulus separately from its physical properties. By so doing, the motivation which determines OR magnitude is seen to be weighted by the relevance of the context, as well as by the physical stimulus characteristics which earlier OR models had given so much importance as determinants of OR strength. Within such a theoretical framework, the small OR magnitude observed for the adults (and possibly also for the infants, although contextual relevance probably operates differently for them) in this study may result from (1) low relevance of the task context for the subjects, since it did not require phonetic processing or any other higher-order cognitive strategies which ordinarily play an important role in their everyday lives; and (2) low salience of the physical stimulus properties, since the adults had presumably been heavily exposed during their 20-odd years to the simple phoneme identities used, and since the stimuli were presented at only moderate intenstiy.

APPENDICES

APPENDIX A

SUBJECT RECRUITMENT MATERIALS

MICHIGAN STATE UNIVERSITY East Lansing, Michigan 48824
Department of Psychology Olds Hall

June 20, 1977

Infant Learning Unit
Developmental Psychobiology Laboratory
Michigan State University

Dear Parent(s):

As recent parents you have probably noticed that your infant already pays attention to various interesting sights and sounds around him/her. Among the sounds that young infants are often particularly attentive to are human speech sounds.

We at the Infant Learning Unit of the Developmental Psychobiology Laboratory at Michigan State University are interested in studying certain aspects of the way infants respond to human speech. As part of an ongoing program of research in infant hearing development, we are conducting studies with infants that deal with their ability to notice differences among various speech sounds. We are now studying three-and-a-half month olds to find out how they are able to attend to and tell the differences among consonant and vowel sounds in speech syllables (such as /pa/ from /ta/, or /tee/ from /tah/).

During the study session with each individual infant, the infant will sit in the parent's lap and listen to a variety of speech syllables over lightweight headphones at a loudness of normal conversation. While the baby is listening to the syllables, we will be keeping a record of his/her heart rate changes. Changes in heart rate tell us whether the baby is paying attention to the sounds. By looking at differences in the heart rate changes to the different syllables, we will be able to tell whether the babies notice the differences among the various syllables. The equipment and sounds we are using in this study have been carefully tested and there is no risk to the babies. This is a scientific study to learn some things about infant hearing that are not yet known, so we will not be able to tell you anything specific about your infant's hearing. But we will of course send the parents who participate information on what we learned from the study about infant hearing. Information about infant hearing gained from studies such as this one may help in developing better tests of infant hearing and infant development, and better tests of these abilities are needed.

We are writing you this letter to ask if you are willing to have your baby take part in this study when he/she is about three-and-a-half months old. If you are willing to bring your baby in one time to be in the study, please fill out and return the enclosed postcard. One of our staff will call you after we have gotten the postcard, to talk to you about the study and answer any questions you may have. We will then try to arrange a convenient time for you to bring the infant in at a time of day when he/she is likely to be awake and alert. We got our information about parents of recently-born infants from local newspaper birth announcements and/or county birth records.

The Infant Learning Unit is located in the Psychology Research Building, Room 103, on the Michigan State University campus. A map has been enclosed showing convenient access routes. If you have any questions or want to talk to us before you return the postcard, feel free to contact either of us at 353-3933. Thank you for your time and consideration.

Sincerely,

Catherine T. Best, Research Director

Hiram E. Fitzgerald, Professor
Department of Psychology

BEST/FITZGERALD INFANT SPEECH PERCEPTION STUDY

I am returning this card to indicate that I am willing to have one of your staff talk with me over the phone about my bringing my baby to the Infant Learning Unit to participate in the Best/Fitzgerald infant speech perception study.

_______________________________ (signature)   __________________ (telephone number)

_______________________________ (print name)

My baby is a __ boy, __ girl, born on ____________________ (baby's birthdate)

The best day(s) for me to bring my baby in for the study is (are): (circle) MON TUES WED THURS FRI WEEKEND

MICHIGAN STATE UNIVERSITY East Lansing, Michigan 48824
Department of Psychology Olds Hall

June 20, 1977

Infant Learning Unit
Developmental Psychobiology Laboratory
Michigan State University

Dear Parent(s):

As recent parents you have probably noticed that your infant already pays attention to various interesting sights and sounds around him/her. Among the sounds that young infants are often particularly attentive to are human speech sounds.

We at the Infant Learning Unit of the Developmental Psychobiology Laboratory at Michigan State University are interested in studying certain aspects of the way infants respond to human speech. As part of an ongoing program of research in infant hearing development, we are conducting studies with infants that deal with their ability to notice differences among various speech sounds. We are now studying three-and-a-half month olds to find out how they are able to attend to and tell the differences among consonant and vowel sounds in speech syllables (such as /pa/ from /ta/, or /tee/ from /tah/).

During the study session with each individual infant, the infant will sit in the parent's lap and listen to a variety of speech syllables over lightweight headphones at a loudness of normal conversation. While the baby is listening to the syllables, we will be keeping a record of his/her heart rate changes. Changes in heart rate tell us whether the baby is paying attention to the sounds. By looking at differences in the heart rate changes to the different syllables, we will be able to tell whether the babies notice the differences among the various syllables. The equipment and sounds we are using in the study have been carefully tested and there is no risk to the babies. This is a scientific study to learn some things about infant hearing that are not yet known, so we will not be able to tell you anything specific about your infant's hearing. But we will of course send the parents who participate information on what we learned from the study about infant hearing. Information about infant hearing gained from studies such as this one may help in developing better tests of infant hearing and infant development, and better tests of these abilities are needed.

We are writing you this letter to ask if you are willing to have your baby take part in this study when he/she is about three-and-a-half months old. One of our staff will call you soon to talk to you about the study and answer any questions you may have. If you are willing to bring your baby in one time to be in the study, we will try to arrange a convenient time for you to bring the infant in at a time of day when he/she is likely to be awake and alert. We got our information about parents of recently-born infants from local newspaper birth announcements and/or county birth records.

The Infant Learning Unit is located in the Psychology Research Building, Room 103, on the Michigan State University campus. A map has been enclosed showing convenient access routes. If you have any questions or want to talk to us before we call you, feel free to contact either of us at 353-3933. Thank you for your time and consideration.

Sincerely,

Catherine T. Best, Research Director	Hiram E. Fitzgerald, Professor Department of Psychology

APPENDIX B

DESCRIPTION OF EXPERIMENTAL PROCEDURES TO PARENTS OF INFANT SUBJECTS

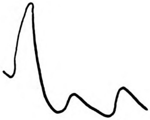
Dear Parent(s):

Recently, scientific investigators have been discovering many interesting facts about the way young infants think and process information. Several investigators have been studying the way infants process the sounds they hear, and particularly the way they respond to human speech sounds. What we learn about the infant's response to speech sounds may help us to both understand the child's natural development of language and to develop better tests for hearing problems in early infancy.

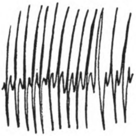
The study in which your infant is about to participate was designed to determine infants' ability to notice the differences among several consonant sounds (such as /p/, /t/, and /k/), and among several vowel sounds (such as /a/, /e/, and /i/). In particular, we are trying to learn whether infants process speech sounds better with the left side of their brains than with the right side, and whether consonants produce a greater left brain advantage than vowels do. Research with adults has shown that most people process speech sounds more efficiently with the left side of their brains than with the right side, while they process music sounds better with the right side of their brains. Recent studies have found this same pattern in three-month-old infants. Furthermore, in adults consonant sounds produce a greater left brain advantage than do vowel sounds, and we want to see whether three-and-a-half month old infants also show this pattern.

The way we learn about the infants' response to the sounds is to play two different speech sounds simultaneously to the two ears at a normal conversation loudness level, over lightweight headphones cleaned with disinfectant. This pair of speech sounds, which are meaningless syllables (example: /pah/, /tah/), will be repeated several times so the infant will learn them; then a new syllable will be played to either the right or left ear. That way we can see whether the infants notice the change in the syllable better with their right or left ear. All infants will hear four of these test sequences, each lasting about three minutes. During the test the infant will sit in your lap in the soundproof chamber. Because we want to be certain that we are learning about the infant's response only to the sounds played over the headphones, we ask that you don't talk to or move the infant (but you can let him/her see your face, or give him/her a bottle or pacifier) once testing has begun. If the infant cries (a common occurrence at this age, and probably related to the strangeness of the situation rather than discomfort from the testing procedures), we will finish the particular test sequence that was begun, since it only lasts three minutes. Then we will take a break between test sequences to try to calm him/her.

In order to detect the infant's responses to the sounds we will be recording the physiological responses of (1) heart rate (EKG), and (2) sweat responses of the skin (skin conductance). Both these responses show changes, called orienting responses, when infants are paying attention to something (adults, too). To study these responses, two sets of recording sensors will be taped to the surface of your infant's skin after the sites have been cleaned with an alcohol wipe. To record heart rate a sensor will be taped on each side of the baby's chest, and above the navel. These sensors will pick up the tiny electrical signals that the baby's heart muscles produce with each beat. These sensors only pick up electrical activity that is naturally present in the body--they cannot produce any electrical activity themselves, and therefore cannot hurt the baby. Sweat gland activity will be monitored by taping a second set of two sensors to the bottom of the baby's left foot. These sensors pick up tiny changes in the electrical properties of the skin associated with sweating. These signals will all be sent to the adjacent room where they will be amplified and converted to lines drawn on moving paper records by a polygraph machine. The attached paper shows what heart rate and skin conductance responses look like when they are recorded this way. The apparatus for recording these responses has been carefully constructed and thoroughly tested so that all potential hazards have been eliminated. There is no danger whatsoever, and your baby will not even feel the sensors.



Skin Conductance



EKG (heart rate)

APPENDIX C

INFORMED CONSENT, MAILING INFORMATION, AND BACKGROUND INFORMATION FORMS FOR PARENTS OF INFANT SUBJECTS

APPENDIX C

INFORMED CONSENT, MAILING INFORMATION, AND BACKGROUND INFORMATION FORMS FOR PARENTS OF INFANT SUBJECTS

PERMISSION FORM FOR TESTING INFANT

Date: ________________

Dear Parent(s):

This form is to request permission for me and/or my staff to examine your infant in tests of attention and perception of different speech sounds. The tests have been approved by the Human Subjects' Committee at Michigan State University and will help researchers to understand the normal development of the young infant's attention to human speech sounds.

You may withdraw permission at any time by simply informing me or one of my staff members that you wish to do so. The information collected is confidential; it will be available only to qualified personnel, and information on individual infants is identified only by number. If you have any questions about the procedures to be used, please feel free to ask them. The tests will not disrupt the infant or in any way be harmful; however, participation in the study will not guarantee you or your infant any beneficial results.

Your signature on this form verifies that the specific tests and procedures to be used with your infant have been explained to your satisfaction, and that you have voluntarily agreed to allow us to test your infant. If at any time you wish to have the data from your baby's participation withdrawn from the experiment, simply advise us and we will destroy all records relevant to your baby.

Sincerely,

Catherine T. Best, Research Director

Hiram E. Fitzgerald, Ph.D.
Professor of Psychology

- -

____
(Parent's signature)

____
(Experimenter's signature)

Follow-up Information

The experiment your infant is participating in is part of a larger research project on infant mental development. Our work is routinely reported in various professional journals and we like to have parents of our subjects aware of the work we are doing. Thus, if you would like to receive follow-up information on the results of the experiment your infant participated in, check the appropriate box below and provide a mailing address that will be good for the next twelve to twenty-four months.

☐ Please send a general summary of the findings (available in about six to nine months)

☐ If articles are published in professional scientific journals I would like to receive copies of the articles.

Mailing Address:

Name: ______________________________

Address: ______________________________

City or Town: ____________ State: ______ Zip: ______

Would you be willing to have one of our staff call you at a later date to see whether you would like to bring your infant in to participate in another study of infant mental development when he/she is a bit older?

☐ yes ☐ no

BACKGROUND INFORMATION SHEET: The information requested in this form will be used to report the general characteristics of the infants used in our research. Only group results will be published, and the identity of individual infants remains anonymous. All information provided on this form will be kept strictly confidential.

Subject Number________________ Test Order____________________

Date of Test__________________ Ear Order_____________________

Time of Day__________ A.M. P.M. (circle) Experimental Condition__________

Experimenters____

Background information on infant

Date of birth ______________________ Sex: Male Female (circle)
Month Day Year

Place of birth____________________, ______________________
City or Town State (or Country, if foriegn)

Weight at birth ___lb. ___oz. Length at birth _______inches

Due date______________________

Any complications during pregnancy? ____ If so, please briefly describe them.

Was medication used during labor and/or delivery (for example, local anesthetic, gas, saddle block)? ______ If so, please briefly describe them.

Any complications during labor and/or delivery (for example, premature, low birth weight, respiratory problems, C-section, etc.)? _____ If so, please briefly describe them.

Is your infant...
_____breast fed ______bottle fed
_____some combination, with bottle feeding ___75% ___ 50% ___25%

Has your infant had any prolonged illness since birth _____? If so, please briefly describe.

Any special problems with ( ) colic, ( ) rashes, ( ) feeding, ( ) sleeping? If so, please briefly describe.

Is there anything else special about your infant that you think it would be important for us to know about for this research project?_____ If so, please briefly describe.

Subject Number________________

Today's schedule and trip to the laboratory

When was your infant last fed?____

When was your infant's last nap?______________________________________

Any break from the infant's routine (other than coming to the laboratory)?_____ If so, please briefly describe.

How long did it take you to get to the laboratory?____________________

In your judgement, was your infant either (a) unusually irritable or excitable today, or (b) unusually quiet today? ___________

Background information on parents and family

Education: Circle the last level of schooling completed, and list any degrees.

	secondary	college	post-graduate	degree(s)
mother:	8 9 10 11 12	13 14 15 16	17 18 19 20 or more	
father:	8 9 10 11 12	13 14 15 16	17 18 19 20 or more	

Occupation:	mother:	Age:	mother:
	father:		father:

Hand Preference (left, right, ambidextrous):

mother:	mother's mother:	father's mother:
father:	mother's father:	father's father:

mother's sisters and brothers:

father's sisters and brothers:

Please list the age, sex, and hand preference of other children in the family:

Age	Sex	Hand Preference

Subject Number________________

Background information on parents and family (continued)

Has there been any type of hearing loss or impairment in your family history (going back to your grandparents and your spouse's grandparents) __________ If so, please briefly describe the problem, and the relative who has/had it.

Has there been any type of speech problem (such as stuttering, late language development, etc.) in your family history (going back to your grandparents and your spouse's grandparents)?__________ If so, please briefly describe the problem, and the relative who has/had it.

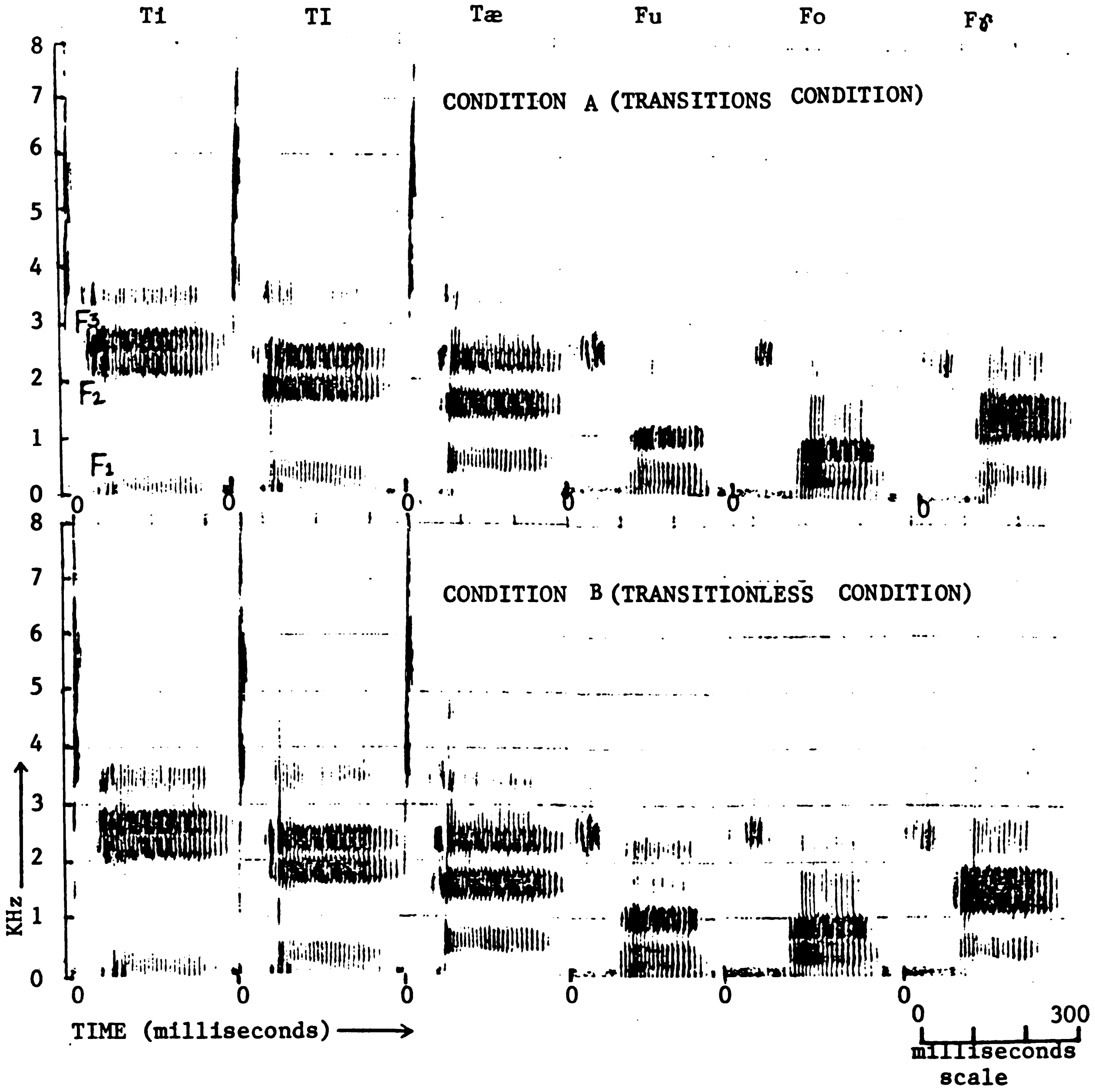


Figure D1. Spectrograms of the stimuli used in Condition A and Condition B for vowel discrimination. The striations correspond to glottal (laryngeal) pulses that occur during voicing. Syllables are identified at the top of the figure, the top spectrogram representing the syllable containing transitions, and the one below it representing the same syllable without transitions. The first three formants are identified in the top left-hand spectrogram.

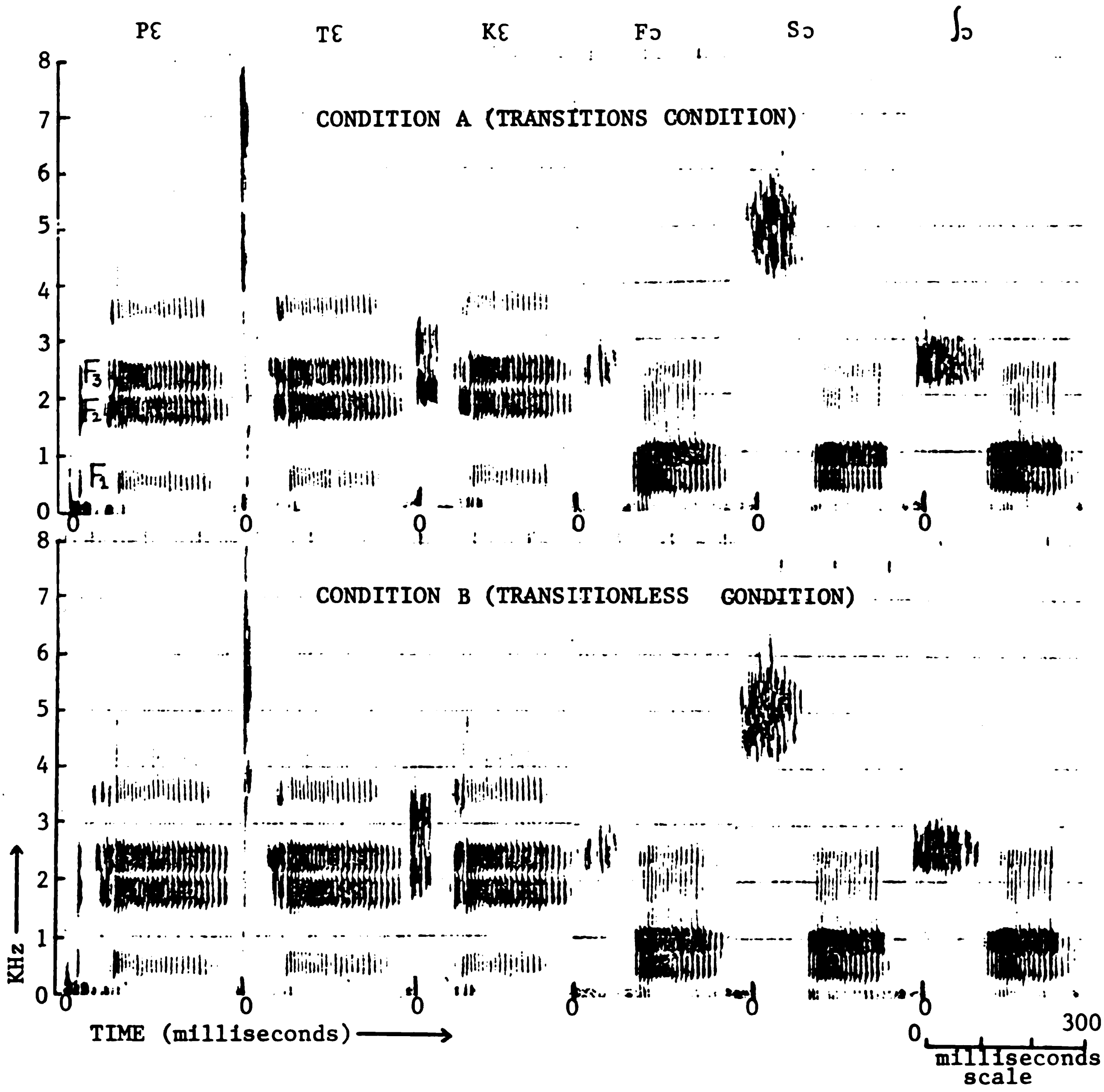


Figure D2. Spectrograms of the stimuli used in Condition A and Condition B for consonant discrimination.

APPENDIX D

ACTUAL SPECTROGRAMS OF THE STIMULUS SYLLABLES

APPENDIX E

DESCRIPTION OF EXPERIMENTAL PROCEDURE TO ADULT SUBJECTS

Dear Subject:

Recently, scientific investigators have been discovering many interesting facts about the way young infants think and process information. Several investigators have begun to study the way infants process auditory information, looking particularly at the way they respond to human speech sounds. What we learn about the infant's response to speech sounds may help us to better understand the child's natural development of language and to devise better tests for auditory problems in infancy such as partial hearing loss. However, in order to make the clearest interpretations of infants' speech perception abilities, the infants' responses to speech sounds must be compared to data on adults' responses to the same speech sounds.

The study in which you are about to participate was designed to measure cerebral asymmetries (cerebral dominance) in the speech perception abilities of three-and-a-half month old infants, and college students' abilities will be used as the adult comparison. Cerebral asymmetry refers to the fact that there are differences between the two human brain hemispheres in the way they respond to and process information. Because we are going to compare what we learn about the infants with what we learn about the young adults in the study, we have tried to make the task for the college students as equivalent as possible to the task for the infants. Therefore, before we start we will only be able to tell you what you will be asked to do during the experiment. We will only be able to explain more about the logic of the study, and what we expect to find with the infants and college students, after you have finished participating.

During the experiment you will hear four series of repeated speech syllables, each series being about three minutes, through a pair of lightweight headphones. The sounds in each series are separated by fairly long silent intervals so that we can get a clear measure of your response to each sound. During each of the four series you will hear a given speech syllable repeated a number of times, and you may or may not hear the syllable change at some point in the series (note: you will hear different syllables repeated in each sequence. By a syllable change we mean that you may, in each series, hear a change from the syllable which that particular series started out with). We ask that you sit quietly without moving your arms or legs, and listen carefully to the sounds in each series. In particular, in each series listen carefully to note whether you hear in change in the syllable that began that series at some point during the repetition, recalling that in each series you may or may not hear a change in the syllable. We will let you know after each series has finished, and when we are starting the next series. Please leave the headphones on, however, until all four series are finished.

In order to detect your responses to the sounds (for comparison to the infants' responses), we will be recording your heart rate and palm sweat responses (skin conductance). To study these responses, two sets of sensors will be taped to the surface of your skin after the recording sites have been cleaned with an alcohol wipe. For heart rate recording a sensor will be taped on each of your wrists, and on your left ankle. These sensors will pick up the tiny electrical signals your heart muscles produce with each beat. Sweat gland activity will be monitored from a second set of sensors taped to the palm of your left hand. These sensors will pick up tiny changes in the electrical properties of the skin associated with sweating. These signals will all be sent to the adjacent room where they will be recorded on a polygraph. We will show you what your record looked like after you have finished the study.

For each series, keep track of whether you heard a syllable change--we will be asking you for this information after you are finished. For example, remember: Series 1 - yes; Series 2 - no; etc.

APPENDIX F

INFORMED CONSENT, MAILING INFORMATION, AND BACKGROUND INFORMATION FORMS FOR ADULT SUBJECTS

Michigan State University
Department of Psychology

DEPARTMENTAL RESEARCH CONSENT FORM

1. I have freely consented to take part in a scientific study being conducted by: CATHERINE BEST

under the supervision of: FITZGERALD

Academic Title: PROFESSOR

2. The study has been explained to me and I understand the explanation that has been given and what my participation will involve.

3. I understand that I am free to discontinue my participation in the study at any time without penalty.

4. I understand that the results of the study will be treated in strict confidence and that I will remain anonymous. Within these restrictions, results of the study will be made available to me at my request.

5. I understand that my participation in the study does not guarantee any beneficial results to me.

6. I understand that, at my request, I can receive additional explanation of the study after my participation is completed.

Signed________________________

Date________________________

Follow-up Information

The experiment you just participated in is part of a larger project on developmental differences in cognitive development, particularly in infancy compared to young adulthood. Our work is routinely reported in various professional journals and we like to have our subjects aware of our findings. Thus, if you would like to receive follow-up information on the results of the experiment you participated in, check the appropriate box below and provide a mailing address that will be good for the next twelve to twenty-four months.

☐ Please send a general summary of the findings (available in about six to nine months)

☐ If articles are published in professional scientific journals I would like to receive copies of the articles.

BACKGROUND INFORMATION SHEET: The information requested in this form will be used to report the general characteristics of the subjects in our study. Only group results will be published, and the identity of individuals remains anonymous. All information provided on this form will be kept confidential.

Subject Number____________________ Test Order________________________

Date of Test______________________ Ear Order_________________________

Time of Day___________ A.M. P.M. Experimental Condition____________
(circle)

Experimenters____

Test information:

Did you hear a change in the speech sounds repeated at some point during:

Sequence 1? ☐ yes ☐ no
Sequence 2? ☐ yes ☐ no
Sequence 3? ☐ yes ☐ no
Sequence 4? ☐ yes ☐ no

Background information on handedness:

Please check the category that most accurately describes your hand preference for each task.

Indicate hand preference:	Always Left	Usually Left	No pre-erence	Usually Right	Always Right
1. To write a letter legibly					
2. To throw a ball to hit a target					
3. To play a game requiring the use of a raquet					
4. At the top of a broom to sweep dust from the floor					
5. At the top (handle) of a shovel to move sand					
6. To hold a match when striking it					
7. To hold scissors to cut paper					
8. To hold thread to guide through the eye of a needle					
9. To deal playing cards					
10. To hammer a nail into wood					
11. To hold a toothbrush while cleaning teeth					

Subject Number__________________

Indicate hand preference	Always Left	Usually Left	No pre-erence	Usually Right	Always Right
12. To unscrew the lid of a jar					
13. To wear a wristwatch					

Age: ________________Years

Background information on parents and family:

Education: Circle the last level of schooling completed, and list any degrees.

	secondary	college	post-graduate	degree(s)
mother:	8 9 10 11 12	13 14 15 16	17 18 19 20 or more	
father:	8 9 10 11 12	13 14 15 16	17 18 19 20 or more	

Occupation: mother: father:

Hand preference (left, right or ambidextrous):

mother:	mother's mother:	father's mother:
father:	mother's father:	father's father:

Please list the sex and hand preference of your siblings (if any):

Has there been any type of hearing loss or impairment in your family history (going back to your grandparents)?______ If so, please briefly describe the problem and the relative who has/had it.

Has there been any type of speech problem (such as stuttering, late language development, etc.) in your family history (going back to your grandparents)?______ If so, please briefly describe the problem and the relative who has/had it.

APPENDIX G

ANALYSIS OF VARIANCE TABLES FOR SIGNIFICANT AND MARGINAL RESULTS

Table G1. ANOVA tables for significant (cut-off = $p<.05$; marginal cut-off = $p<.10$) results in all analyses. Those results not reported in the Results section of the main body are marked with a *. Those not reported in the Results section or involved in the effects of the reported results are irrelevant to test predictions or otherwise not of theoretical interest to the present discussion or are apparently meaningless as well as likely irreplicable. The latter are indicated by lower-case letter superscripts, for table footnotes briefly describing the nature of the effect. The key for the factor identification symbols is:

S = Seconds
T = Trials
E = Ear tested
G = Gender
I = Individual subjects
P = Phoneme (vowel or consonant test)
D = Dishabituation subgroup (Group H infants, Condition A)

Source	Error term	df	SS	MS	F	p
Adults, Condition A - Trials 1 through 9:						
S*	IxS(G)	9	1074.27	119.36	4.18	.0005
IxS(G)		126	3601.37	28.58		
T*	IxT(G)	8	2396.92	299.64	1.82	.08
IxT(G)		112	18429.60	164.64		
SxT*	IxSxT(G)	72	1203.21	16.71	1.24	.09
IxSxT(G)		1008	13545.60	13.44		
SxGxE[a]	IxSxE(G)	9	432.05	48.01	2.89	.004
IxSxE(G)		126	2086.88	16.56		

[a] - Summed over trials 1 through 9, the evoked poststimulus heart rate response was slightly decelerative for males in test sequences destined to have a left ear test on trial 10; the summed evoked heart rate response for male right ear tests, and for both ears tested for females, was slightly accelerative.

Source	Error term	df	SS	MS	F	p
Adults, Condition A - Trials 1 and 9:						
S	IxS(G)	9	356.48	38.61	2.04	.04
IxS(G)		126	2444.16	19.39		
T*	IxT(G)	1	808.83	808.83	5.00	.04
IxT(G)		14	2264.06	161.72		
SxTxP[b]	IxSxTxP(G)	9	133.58	14.84	1.99	.05
IxSxTxP(G)		126	937.79	7.44		
SxTxE[c]	IxSxTxE(G)	9	271.41	30.16	2.29	.02
IxSxTxE(G)		126	1654.79	13.13		

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Table G1 (continued)

Adults, Condition A - Trials 1 and 9 (continued):

[b] - The trial 1 response was decelerative for both vowel and consonant discrimination tests, although somewhat larger for consonant tests; the trial 9 response for vowel tests was a smaller deceleration than seen on trial 1, and was not decelerative for consonant tests.

[c] - The evoked poststimulus heart rate response on trial 1 was decelerative for both left ear and right ear tests; the trial 9 response was decelerative for right ear test sequences, but was not decelerative for left ear tests.

Adults, Condition A - Trial 9:

Source	Error term	df	SS	MS	F	p
SxP[d]	IxSxP(G)	9	183.74	20.42	2.29	.02
IxSxP(G)		126	1122.74	8.91		

[d] - There was a small deceleration immediately and briefly following vowel test presentations on trial 9, but none for consonant test presentations on this trial. See Figure G1 for illustration, as well as Figure 10 in the main body of the Results.

Adults, Condition A - Trials 9 and 10:

Source	Error term	df	SS	MS	F	p
S	IxS(G)	9	461.58	51.29	3.09	.002
IxS(G)		126	2019.98	16.60		
TxG[e]	IxT(G)	1	701.96	701.96	8.33	.01
IxT(G)		14	1179.86	84.28		
TxP*	IxTxP(G)	1	479.34	479.34	5.29	.04
IxTxP(G)		14	1290.95	92.21		
SxTxP*	IxSxTxP(G)	9	217.00	24.11	3.04	.003
SxTxGxP[d,f]	"	9	184.32	20.48	2.58	.009
IxSxTxP(G)		126	999.29	7.93		

[e] - Summed over the trials 9 vs. 10 responses to both vowel and consonant changes on trial 10, males showed evidence of test trial dishabituation whereas females did not; however, other findings indicate that females dishabituated to the vowel change, which was negated in this result by their large trial 10 heart rate acceleration to the consonant change. Males, on the other hand, did not show a trial 10 acceleration to the consonant change, thus their trial 10 response summed over phonemes was decelerative. See Figure G1.

(continued next page)

Table G1 (continued)

Source	Error term	df	SS	MS	F	p
Adults, Condition A - Trials 9 and 10 (continued):						
[f] - See Figure G1.						
Adults, Condition A - Trial 10 (test):						
S^*	IxS(G)	9	312.78	34.75	2.54	.01
SxG^g	"	9	259.46	28.83	2.11	.04
IxS(G)		126	1723.33	13.68		
P^*	IxP(G)	1	858.40	858.40	4.24	.059
GxP^e	"	1	1053.70	1053.70	5.20	.04
IxP(G)		14	2834.48	202.46		
[g] - Both males and females showed a trial 10 decelerative response, summed over the two phonemes, but the males showed decelerations that were slightly larger and longer.						
Adults, Condition B - Trials 1 through 9:						
S^*	IxS(G)	9	2519.37	279.93	5.76	.0005
IxS(G)		126	6119.69	48.57		
T^*	IxT(G)	8	4002.88	500.36	3.00	.004
IxT(G)		112	18656.10	166.57		
Adults, Condition B - Trials 1 and 9:						
T^*	IxT(G)	1	1677.88	1677.88	13.66	.002
IxT(G)		14	1725.88	123.28		
TxE^h	IxTxE(G)	1	1575.53	1575.53	4.58	.05
IxTxE(G)		14	4815.92	343.99		
$GxPxE^i$	IxPxE(G)	1	827.38	827.38	7.97	.014
IxPxE(G)		14	1454.28	103.88		

[h] - There was a larger decelerative response on trial 1 for the right ear tests than for the left ear tests, and an accelerative response on trial 9 for the right ear tests whereas there was a small deceleration on trial 9 for the left ear tests.

[i] - Meaningless.

(continued next page)

Table G1 (continued)

Source	Error term	df	SS	MS	F	p
Adults, Condition B - Trial 9:						
SxG[j]	IxS(G)	9	487.29	54.14	2.58	.009
IxS(G)		126	2648.88	21.02		
E[k]	IxE(G)	1	1017.58	1017.58	5.99	.03
IxE(G)		14	2377.17	169.79		

[j] - Meaningless, since the G main effect was nonsignificant.

[k] - There was a trial 9 accelerative response for right ear tests, and a small (nonsignificant) decelerative response for left ear tests.

Source	Error term	df	SS	MS	F	p
Adults, Condition B - Trials 9 and 10:						
S[l]	IxS(G)	9	932.99	103.67	3.15	.002
IxS(G)		126	4146.63	32.91		
P	IxP(G)	1	1082.84	1082.84	5.57	.033
IxP(G)		14	2723.26	194.52		
E[m]	IxE(G)	1	1539.35	1539.35	5.17	.04
IxE(G)		14	4166.35	297.59		
SxTxG	IxSxT(G)	9	662.75	72.64	3.47	.001
IxSxT(G)		126	2674.31	21.22		
SxP	IxSxP(G)	9	235.89	26.21	2.18	.03
IxSxP(G)		126	1515.43	12.03		

[l] - Summed over trials 9 and 10, the evoked poststimulus heart rate response for left ear tests was a small deceleration, whereas the response for right ear tests was a small acceleration -- meaningless, since summed over the last habituation trial and the test trial.

[m] - Also meaningless, since the TxG interaction was nonsignificant.

Source	Error term	df	SS	MS	F	p
Adults, Condition B - Trial 10:						
S*	IxS(G)	9	673.87	74.87	2.26	.022
IxS(G)		126	4172.06	33.11		
P*	IxP(G)	1	1332.58	1332.58	6.02	.03
IxP(G)		14	3008.12	214.87		

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Table G1 (continued)

Source	Error term	df	SS	MS	F	p
Infants (Total sample), Condition A - Trials 1 through 9:						
S*	IxS(G)	9	1616.18	179.58	2.21	.025
IxS(G)		126	10219.90	81.11		
GxP[n]	IxP(G)	1	1509.93	1509.93	6.11	.03
IxP(G)		14	3460.75	274.19		
SxGxE[o]	IxSxE(G)	9	854.60	94.96	2.43	.014
IxSxE(G)		126	4930.28	39.13		
SxTxGxP[o]	IxSxTxP(G)	72	2496.40	34.67	1.34	.04
IxSxTxP(G)		1008	26090.10	25.88		
SxTxGxE[o]	IxSxTxE(G)	72	2803.03	38.93	1.38	.023
IxSxTxE(G)		1008	28449.60	28.22		

[n] - Summed over trials 1 through 9, males showed a small decelerative response for vowel test trials but not for consonant test trials, whereas the converse was true for females.

[o] - All meaningless, since GxE, TxGxE, TxGxP interactions were all nonsignificant.

Infants (Total sample), Condition A - Trials 1 and 9:						
S[p]	IxS(G)	9	808.49	89.83	2.17	.03
IxS(G)		126	5229.14	41.50		
GxP[q]	IxP(G)	1	2509.36	2509.36	5.47	.04
IxP(G)		14	6422.47	458.75		

[p] - Summed over trials 1 and 9, there was a cardiac deceleration response.

[q] - Summed over the two trials, females showed a decelerative response during consonant tests but not vowel tests, whereas the converse was true for males.

Infants (Total sample), Condition A - Trial 9:						
S*	IxS(G)	9	676.94	75.22	2.20	.03
IxS(G)		126	4308.10	34.19		
SxGxE[r]	IxSxE(G)	9	580.31	64.48	2.05	.04
IxSxE(G)		126	3970.96	31.52		

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Table G1 (continued)

Infants (Total sample), Condition A - Trial 9 (continued):

[r] - Of no consequence, since the G main effect and GxE interaction are nonsignificant.

Infants (Total sample), Condition A - Trials 9 and 10:

Source	Error term	df	SS	MS	F	p
TxGxP[s]	IxTxP(G)	1	1599.59	1599.59	6.76	.02
IxTxP(G)		14	3310.63	236.47		
SxTxP[t]	IxSxTxP(G)	9	386.93	42.99	2.01	.04
IxSxTxP(G)		126	2697.26	21.41		

[s] - Some evidence of trial 10 dishabituation on consonant tests for males, but not for vowels, nor for trial 10 dishabituation on either test for females (largely because of a large trial 9 deceleration for females).

[t] - Some evidence of trial 10 dishabituation for consonant tests, but not for vowel tests (because of a large trial 9 deceleration during the vowel test sequences).

Infants (Total sample), Condition A - Trial 10:

Source	Error term	df	SS	MS	F	p
GxP[u]	IxP(G)	1	2155.02	2155.02	6.87	.02
IxP(G)		14	4390.98	313.64		

[u] - There was a decelerative response by females on the vowel tests for trial 10, but not for the consonant tests; the converse was true for males.

Infants (Total sample), Condition B - Trials 1 through 9:

Source	Error term	df	SS	MS	F	p
S*	IxS(G)	9	5010.10	556.68	7.24	.0005
IxS(G)		126	9691.31	76.92		
SxTxG[v]	IxSxT(G)	72	3034.51	42.25	1.53	.004
IxSxT(G)		1008	27848.30	27.63		
TxGxE[v]	IxTxE(G)	8	8322.17	8322.17	2.31	.025
IxTxE(G)		112	50466.90	450.59		
SxTxGxPxE[v]	IxSxTxP(G)	72	2673.07	37.13	1.51	.005
IxSxTxP(G)		1008	24797.70	24.60		

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Table G1 (continued)

Source	Error term	df	SS	MS	F	p
Infants (Total sample),Condition B - Trials 1 through 9:						
^{v} - All meaningless, since the G, P, E, T main effects and TxG, GxE and TxGxPxE interactions are nonsignificant.						
Infants (Total sample), Condition B - Trials 1 and 9:						
S*	IxS(G)	9	1097.21	121.91	3.30	.001
IxS(G)		126	4655.26	36.95		
SxGxE^{w}	IxSxE(G)	9	714.85	79.43	2.14	.03
IxSxE(G)		126	4684.07	37.18		
^{w} - Meaningless, since G and E main effects and GxE interaction are nonsignificant.						
Infants (Total sample), Condition B - Trial 9:						
S*	IxS(G)	9	1225.73	136.19	4.33	.0005
IxS(G)		126	3967.79	31.49		
SxGxE^{x}	IxSxE(G)	9	842.75	93.64	3.58	.001
IxSxE(G)		126	3292.03	26.13		
^{x} - Meaningless, since no significant G or E main effects, or GxE interaction.						
Infants (Total sample), Condition B - Trials 9 and 10:						
S*	IxS(G)	9	1581.54	175.73	3.08	.002
IxS(G)		126	7187.15	57.04		
SxT*	IxSxT(G)	9	565.62	62.85	2.03	.04
IxSxT(G)		126	3896.39	30.92		
SxGxE^{y}	IxSxE(G)	9	888.60	98.73	3.69	.0005
IxSxE(G)		126	3372.33	26.76		
PxE^{z}	IxPxE(G)	1	3207.41	3207.41	9.91	.007
IxPxE(G)		14	4529.52	323.54		
SxTxGxE^{y}	IxSxTxE(G)	9	540.11	60.01	3.16	.002
IxSxTxE(G)		126	2395.22	19.01		
SxPxE^{z}	IxSxPxE(G)	9	1103.71	122.64	3.19	.002
IxSxPxE(G)		126	4840.61	38.42		

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Table G1 (continued)

Source	Error term	df	SS	MS	F	p

Infants (Total sample), Condition B - Trials 9 and 10:

[y] - Meaningless, since G, E, T main effects and GxE and TxGxE interactions are nonsignificant.

[z] - Meaningless, since summed over trials 9 and 10.

Infants (Total sample), Condition B - Trial 10:

Source	Error term	df	SS	MS	F	p
S[aa]	IxS(G)	9	921.43	102.38	1.81	.07
IxS(G)		126	7115.75	56.47		
SxGxE	IxSxE(G)	9	585.97	65.11	3.13	.001
IxSxE(G)		126	2475.52	19.65		
PxE*	IxPxE(G)	1	2364.68	2364.68	4.66	.05
IxPxE(G)		14	7112.51	508.03		
SxPxE*	IxSxPxE(G)	9	788.23	87.58	2.57	.01
IxSxPxE(G)		126	4297.92	34.11		

[aa] - Summed over vowel and consonant tests, neither gender showed a trial 10 decelerative response during left ear tests, while showing a decelerative response to right ear tests which was larger for males than for females.

Infants (Group H), Condition A - Trials 1 through 9:

Source	Error term	df	SS	MS	F	p
S*	IxS(PxE)	9	1382.20	153.58	3.42	.0005
IxS(PxE)		351	15770.30	44.93		
T*	IxT(PxE)	8	4495.10	561.89	2.08	.04
IxT(PxE)		312	84331.20	270.29		

Infants (Group H), Condition A - Trials 1 and 9:

Source	Error term	df	SS	MS	F	p
S*	IxS(PxE)	9	1235.00	137.22	5.83	.0005
IxS(PxE)		351	8266.93	23.55		
T*	IxT(PxE)	1	864.56	864.56	4.31	.044
TxE[bb]	"	1	867.58	867.58	4.33	.044
IxT(PxE)		39	7819.35	49.37		
SxT*	IxSxT(PxE)	9	397.31	44.51	2.81	.003
IxSxT(PxE)		351	5512.04	15.70		

[bb] - On trial 1 the subjects showed a deceleration during the left ear tests and small acceleration during the right ear tests, but showed accelerations on trial 9 for both left and right ear tests.

(continued next page)

Table G1 (continued)

Source	Error term	df	SS	MS	F	p
Infants (Group H), Condition A - Trial 9:						
S*	IxS(PxE)	9	1450.22	161.14	7.96	.0005
IxS(PxE)		351	7105.92	20.24		
Infants (Group H), Condition A - Trials 9 and 10:						
T*	IxT(PxE)	1	3440.37	3440.37	10.48	.002
IxT(PxE)		39	12802.40	328.27		
SxT*	IxSxT(PxE)	9	1371.70	152.41	6.58	.0005
IxSxT(PxE)		351	7809.48	22.25		
Infants (Group H: Subgroups), Condition A - Trials 9 and 10:						
S*	IxS(PxExD)	9	445.91	49.55	2.38	.013
SxD*	"	9	736.19	81.79	3.93	.0005
SxDxE*	"	9	518.77	57.64	2.77	.004
IxS(PxExD)		315	6549.89	20.79		
T*	IxT(PxExD)	1	2627.96	2627.96	11.55	.002
TxD*	"	1	4497.15	4497.15	19.77	.0005
IxT(PxExD)		35	7963.73	227.54		
D*	I(PxExD)	1	5548.39	5548.39	25.72	.0005
I(PxExD)		35	7551.77	215.77		
SxT*	IxSxT(PxExD)	9	1149.45	127.72	5.82	.0005
SxTxD*	"	9	359.96	39.99	1.82	.064
IxSxT(PxExD)		315	6918.96	21.96		
Infants (Group H: Subgroups), Condition A - Trial 10:						
SxD*	IxS(PxExD)	9	970.47	107.83	5.02	.0005
SxExD	"	9	537.12	59.68	2.78	.004
SxPxDxE	"	9	432.63	48.07	2.24	.02
IxS(PxExD)		315	6763.17	21.47		
D*	I(PxExD)	1	10018.00	10018.00	67.09	.0005
I(PxExD)		35	5226.51	149.33		
Infants (Group H), Condition B - Trials 1 through 9:						
S*	IxS(PxE)	9	3277.35	364.15	7.75	.0005
IxS(PxE)		378	17756.80	46.98		
T*	IxT(PxE)	8	6957.09	869.64	1.99	.046
IxT(PxE)		336	146287.00	435.38		

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Table G1 (continued)

Source	Error term	df	SS	MS	F	p
Infants (Group H), Condition B - Trials 1 through 9:						
$SxTxPxE^{cc}$	IxSxT(PxE)	72	2576.00	35.78	1.38	.02
IxSxT(PxE)		3024	78420.50	25.93		
^{cc} - Meaningless, since P, E main effects and PxE and TxPxE interactions are nonsignificant.						
Infants (Group H), Condition B - Trials 1 and 9:						
S^*	IxS(PxE)	9	1217.31	135.28	4.15	.0005
IxS(PxE)		378	12311.60	32.57		
Infants (Group H), Condition B - Trial 9:						
S^*	IxS(PxE)	9	1012.24	112.47	4.07	.0005
IxS(PxE)		378	10456.40	27.66		
Infants (Group H), Condition B - Trials 9 and 10:						
S	IxS(PxE)	9	780.07	86.74	2.58	.007
$SxPxE^{dd}$	"	9	940.10	104.46	3.10	.001
IxS(PxE)		378	12732.70	33.68		
T^*	IxT(PxE)	1	4188.10	4188.10	10.52	.002
IxT(PxE)		42	16705.80	397.76		
PxE^{cc}	I(PxE)	1	2094.39	2094.39	6.49	.015
I(PxE)		42	13544.00	322.48		
SxT^*	IxSxT(PxE)	9	1134.62	126.07	4.70	.0005
IxSxT(PxE)		378	10133.80	26.81		
^{dd} - Meaningless.						
Infants (Group H), Condition B - Trial 10:						
S^*	IxS(PxE)	9	903.06	100.03	3.06	.002
$SxPxE^*$	"	9	999.96	111.11	3.38	.001
IxS(PxE)		378	12410.10	32.83		
PxE^*	I(PxE)	1	2917.32	2917.32	5.84	.02
I(PxE)		42	20953.50	498.89		

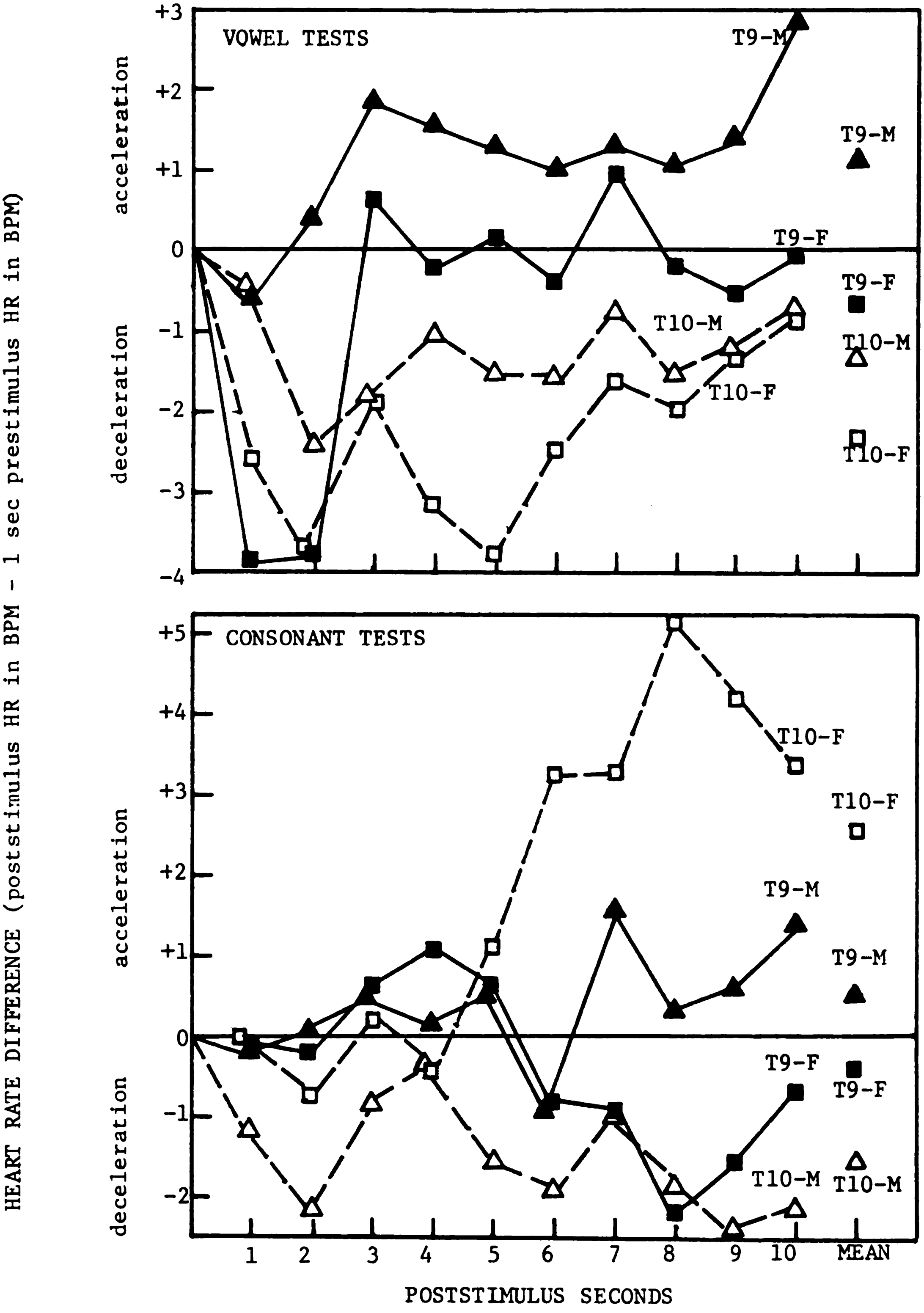

Figure G1. Second-by-second evoked poststimulus heart rate responses, and mean heart rate difference scores, on trials 9 (T9) and 10 (T10), during the Consonant (C) and Vowel (V) tests, for the male (M) and female (F) adults in Condition A (Transitions Condition).

APPENDIX H

TABLES OF TRIALS 9 AND 10 HEART RATES FOR DISHABITUATING AND NONDISHABITUATING INFANTS INCLUDED IN GROUP H ANALYSES

Table H1. Mean heart rate difference scores (mean of the 10 poststimulus seconds) on trials 9 and 10, during the Left Ear and Right Ear tests of Consonant and Vowel discrimination, for all individual infants. Those tests chosen for inclusion in the Group H analyses are underlined and marked, a # indicating that the individual was deemed to show dishabituation on trial 10 relative to his trial 9 response, and a * indicating lack of dishabituation by the individual on that test (see table footnotes for lower-case letter superscripts).

CONDITION A (TRANSITIONS CONDITION)

	Vowel-Left Ear:		Vowel-Right Ear:		Consonant-Left Ear:		Consonant-Right Ear:	
Subjects:	Trial 9	Trial 10	Trial 9	Trial 10	Trial 9	Trial 10	Trial 9	Trial 10
MALES:								
121	- 1.03[a]	+ 4.09*	+ 6.03	- 9.38#	+ 2.85	+ 4.53*	+ 1.63	- 6.75#
125	- 2.09[a]	- 3.10#	-13.84	- 1.80	- .70	- 8.07#	- 1.97[a]	- 3.67#
127	+ 4.69	+ 8.13*	- .93[b]	- .75	- 1.47[a]	- 3.91#	- 3.35[a]	- 2.67*
129	0	+ .16*	+ .38	+ .55*	- .95	-11.82#	-14.81	- 9.01
130	-16.71	- 8.68	-29.20	- .79	-15.72	- 5.60	- 1.51[b]	- 1.58
116	+ 3.69	+ 4.77*	+ 1.09	+ 2.16*	+ 8.55	+ 2.23*	+13.33	- 3.68#
139	+ 8.38	- 5.05#	+ .12	- 2.88#	+ 1.65	- 8.99#	+11.16	+ 1.58*
132	+ 2.95	+ 4.74*	+ 3.33	+ 5.97*	+ 2.53	+ 1.54*	+ .56	- 9.04#
FEMALES:								
12	+ 7.12[c]	+ 4.31	-12.64	- 1.17	-10.44[d]	- 2.25*	- 3.20[a]	+15.94
19	-11.47	+ 6.64	+11.96	-13.77#	+ 6.40[c]	- 2.19	+ 6.27	+ 8.77*
25	+14.97	-10.61#	- 1.58[a]	-10.13#	+ 5.82	- 1.71#	- 4.21	+ 5.63
26	- 5.41	0	-10.69[e]	-12.55#	- 3.92[a]	+ 5.13*	- 4.90	- 2.50

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Table H1 (continued)

Subjects:	Vowel-Left Ear: Trial 9	Vowel-Left Ear: Trial 10	Vowel-Right Ear: Trial 9	Vowel-Right Ear: Trial 10	Consonant-Left Ear: Trial 9	Consonant-Left Ear: Trial 10	Consonant-Right Ear: Trial 9	Consonant-Right Ear: Trial 10
				CONDITION A (TRANSITIONS CONDITION)				
FEMALES:								
29	- 2.25	+ 2.41	+ .57	- 4.61$^{\#}$	+ 1.45	- 1.58$^{\#}$	+ 1.32	- .32*
33	-14.08	+11.05	- 3.78	- 3.55	- 2.84	- .62	- 1.04^{b}	+ 1.38
32	- 1.56^{a}	- 4.48$^{\#}$	+ 2.32	+14.07*	-12.69	+ 3.68	+ 1.91	- 2.67$^{\#}$
41	- 1.06^{a}	- 3.65$^{\#}$	+ .61	- 1.79$^{\#}$	- 1.77^{a}	+ 1.46*	+ 2.48	+ 6.47*
				CONDITION B (TRANSITIONLESS CONDITION)				
MALES:								
113	- 1.53^{a}	- 3.49$^{\#}$	+ 6.24^{c}	+ 5.11	+ 5.19	+ 2.56*	- 1.10^{a}	- 2.18$^{\#}$
122	+ .78	- 1.42$^{\#}$	+ .36	+ 3.49*	+ 2.70	- 1.19$^{\#}$	- 2.26	+ 3.11
126	-10.52	- 6.11	+ 3.16	+ 4.88*	+ 3.30	+ 9.31*	- 2.55^{a}	- 6.36$^{\#}$
128	- .29	- 4.86$^{\#}$	+ 2.64	- 8.26$^{\#}$	+12.56	-13.49$^{\#}$	-13.24	-15.72
133	- 9.64	+16.38	+ .66	+ 5.36*	- 2.13^{a}	- .35*	- 2.11^{b}	+ 1.74
135	+ 2.59	- 5.59$^{\#}$	- 2.23^{a}	- 5.46$^{\#}$	- 4.66	+ 2.35	+ 2.31^{f}	- .64$^{\#}$
140	+15.40	- 2.36$^{\#}$	- 3.09^{a}	- 9.08$^{\#}$	- 2.11^{a}	+12.52*	- 1.53^{a}	- 2.08$^{\#}$
142	+ 2.03	- 3.50$^{\#}$	- 1.06^{a}	+23.52*	+ 2.99^{f}	- .77$^{\#}$	- 4.01	- 4.92
FEMALES:								
14	+ 1.11	- 6.37$^{\#}$	+ 4.10	+ 5.47*	- 3.10^{a}	- .68*	-15.61	+ 3.02

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Table H1 (continued)

CONDITION B (TRANSITIONLESS CONDITION)

Subjects:	Vowel-Left Ear: Trial 9	Vowel-Left Ear: Trial 10	Vowel-Right Ear: Trial 9	Vowel-Right Ear: Trial 10	Consonant-Left Ear: Trial 9	Consonant-Left Ear: Trial 10	Consonant-Right Ear: Trial 9	Consonant-Right Ear: Trial 10
FEMALES:								
22	+ 3.27	- 1.06#	+14.00	- 3.12#	- 1.92[a]	+ 1.98*	- 7.49[a]	- .65#
23	+ 4.24	- 2.66#	- 5.05	+ 3.03	- 5.17	+ 5.66	+ 3.75	-17.65#
24	- .90	+ .33*	- .36	- 4.31#	+ .63	+ .13*	- .79	- .13*
27	- 9.78	- 2.01	- 4.02	- 3.32	+ 2.90	+ 5.48*	+ 3.64	-12.72#
35	-13.04	+ .81	+ 2.10	-17.43#	+ .51[c]	- 1.49	- 3.93[a]	-11.03#
36	+ .46	- 2.17#	- 5.26	+ 6.63	+ 4.79	- .08*	- .78	-12.76#
37	- .22[b]	+ 2.34	-11.30	- 9.99	+10.99	+ 6.86*	- 3.29[a]	- 7.96#

[a] - Although there were small ORs on trial 9 for these tests, the ORs were smaller than ORs seen on earlier trials of the given test sequence, indicating that habituation occurred.

[b] - Although the trial 9 OR was small, it was about the same magnitude as ORs on earlier trials of the given test sequence, suggesting that habituation did not occur.

[c] - Although there was no OR on trial 9, neither were there ORs on earlier trials of the given test sequence, suggesting no habituation of ORs.

[d] - Very late onset of the trial 10 deceleration suggested that it was not clearly stimulus-related;therefore, the infant was not considered to have dishabituated on this test sequence.

[e] - In this case, the trial 9 OR was large, yet was smaller than earlier ORs in this test sequence, which had noticeably diminished by trial 7 (thus habituation was felt to have occurred).

[f] - Although the mean trial 10 OR was small, its onset portion was relatively large and similar to ORs on earlier trials; furthermore, the trial 10 response was noticeably decelerative relative to trial 9.

Table H2. Second-by-second evoked poststimulus heart rate response curves on trial 10, during Left Ear and Right Ear Consonant and Vowel tests, for the Group H infants in Condition A (Transitions Condition). Individuals are categorized according to whether or not they showed dishabituation of the cardiac OR on trial 10 relative to their cardiac response on trial 9 of the given test sequence (M = male, F = female).

VOWEL TESTS

	Poststimulus seconds:										
Subject:	1	2	3	4	5	6	7	8	9	10	Mean(10 sec)
RIGHT EAR TESTS:											
Dishabituation Subgroup (D):											
19(F)	+ 1.3	+ 1.7	- 4.5	-10.8	-14.1	-19.2	-13.2	-19.4	-27.0	-32.5	-13.77
121(M)	- 7.3	- 9.8	-13.6	-13.4	-10.3	- 8.4	- 6.2	- 6.2	- 6.7	-11.9	- 9.38
25(F)	+ .8	+ .7	- 2.0	- 2.0	- 9.8	-14.5	-17.7	-21.0	-18.4	-17.4	-10.13
26(F)	- 3.3	- 7.8	-12.1	-15.5	-14.7	-14.5	-13.3	-13.6	-10.6	-20.1	-12.55
29(F)	- .4	- .7	- 2.5	- 2.0	- 3.6	- 5.9	- 6.7	- 8.6	- 8.6	- 7.1	- 4.61
139(M)	- 5.0	- 2.8	- 3.8	- 5.3	- 6.9	- 4.1	- .9	+ .7	- .4	- .3	- 2.88
41(F)	- .7	- 2.6	- 4.5	- 5.7	- 4.3	- 2.9	- .4	- .1	+ 1.7	+ 1.6	- 1.79
WTD. AVE.[a]	- 2.14	- 3.29	- 6.24	- 7.93	- 9.16	-10.47	- 9.29	-11.36	-12.50	-15.08	- 8.75
Nondishabituation Subgroup (N):											
129(M)	- 1.5	+ .5	+ 1.7	+ 3.6	+ 3.7	+ 1.9	+ .2	- 1.3	- .3	- 3.0	+ .55
116(M)	- 2.3	- 1.2	+ .3	+ .2	+ 2.7	+ 2.8	+ 2.8	+ 3.4	+ 5.5	+ 7.4	+ 2.16
32(F)	+ .7	- .3	+ .70	+12.0	+16.7	+18.4	+18.6	+21.1	+23.1	+23.4	+14.07
132(M)	+ 1.5	+ 6.2	+ 6.6	+ 6.0	+ 2.9	+ 1.1	+ 3.6	+ 7.3	+ 9.8	+12.9	+ 5.79
WTD. AVE.	- .40	+ 1.30	+ 3.90	+ 5.45	+ 6.50	+ 6.05	+ 6.30	+ 7.63	+ 9.53	+10.18	+ 5.64
LEFT EAR TESTS:											
Dishabituation Subgroup (D):											
125(M)	- 2.1	- 2.9	- 3.4	- 4.6	- 6.3	- 5.0	- 4.9	- 2.1	+ .2	+ .1	- 3.10
25(F)	-10.4	-11.9	-14.7	-17.0	-17.1	-14.2	- 9.0	- 5.1	- 1.9	- 4.8	-10.61
139(M)	- 6.3	- 3.2	- 2.1	- 3.6	- 5.4	- 5.0	- 4.2	- 4.9	- 7.3	- 8.5	- 5.05

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Table H2 (continued)

VOWEL TESTS

Subject:	Poststimulus seconds: 1	2	3	4	5	6	7	8	9	10	Mean(10 sec)
LEFT EAR TESTS:											
Dishabituation Subgroup (D):											
32(F)	- 9.9	- 1.0	+ .9	+ .9	- 3.5	- 7.0	- 8.8	- 6.2	- 5.7	- 4.5	- 4.48
41(F)	+ .3	- 6.8	- 7.7	- 4.4	- 3.9	- 3.4	- 4.1	- 3.7	- 2.5	- .3	- 3.65
WTD. AVE.	- 5.42	- 5.08	- 5.74	- 6.08	- 7.54	- 6.74	- 5.54	- 3.28	- 2.06	- 1.96	- 4.94
Nondishabituation Subgroup (N):											
121(M)	+ .5	+ 6.4	+ 9.2	+ 8.5	+ 8.8	+ 4.4	- 1.1	+ .4	+ 1.8	+ 2.0	+ 4.09
127(M)	+ 2.9	+ 7.6	+ 9.3	+ 8.1	+ 8.0	+10.5	+ 9.1	+ 9.3	+ 8.3	+ 8.2	+ 8.13
129(M)	- .1	- .6	+ 1.1	+ .7	+ .5	- 1.1	- .3	+ 1.1	- .1	+ .4	+ .16
116(M)	+ .5	+ 2.9	+ 4.0	+ 5.4	+ 6.6	+ 8.2	+ 9.5	+ 8.2	+ 3.0	- .6	+ 4.77
132(M)	-11.5	+ 5.2	+15.5	+11.5	+ 9.2	+ 8.0	+ 4.4	+ 3.5	+ 2.7	- 1.1	+ 4.74
WTD. AVE.	- 1.54	+ 4.30	+ 7.82	+ 6.85	+ 6.62	+ 6.00	+ 4.32	+ 4.50	+ 3.14	+ 1.78	+ 4.38

CONSONANT TESTS

Subject:	1	2	3	4	5	6	7	8	9	10	Mean(10 sec)
RIGHT EAR TESTS:											
Dishabituation Subgroup (D):											
121(M)	- 1.9	-10.1	-13.6	-17.4	-10.9	- 7.0	- 4.2	- 2.9	+ .6	- .1	- 6.75
125(M)	- 1.0	- 1.8	- 3.0	- 5.2	- 3.4	- 3.1	- 2.3	- 5.2	- 6.7	- 5.0	- 3.67
116(M)	+ 1.5	+ 2.5	+ 3.4	+ 1.6	- 2.4	- 7.8	- 5.1	- 6.8	-10.4	-13.3	- 3.68
32(F)	+ .9	- 1.0	- 2.5	- 2.7	- 6.3	- 7.1	- 5.5	- 2.7	+ .7	- .5	- 2.67
132(M)	- 2.8	- 1.0	+ 3.5	- 4.4	-13.4	-15.1	-14.4	-14.3	-14.5	-14.0	- 9.04
WTD. AVE.	- .66	- 2.28	- 2.44	- 5.62	- 7.28	- 8.02	- 6.30	- 6.38	- 6.06	- 6.58	- 5.16
Nondishabituation Subgroup (N):											
19(F)	+ 3.3	+ 7.3	+ 9.8	+15.2	+14.7	+14.6	+15.1	+10.3	+ 1.9	- 4.5	+ 8.77
127(M)	+ .9	+ .1	- 1.8	- .6	- 4.1	- 5.3	- 7.5	- 6.2	- 2.0	- .2	- 2.67[b]

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Table H2 (continued)

CONSONANT TESTS

Subject:	Poststimulus seconds: 1	2	3	4	5	6	7	8	9	10	Mean(10 sec)
Nondishabituation Subgroup (N):											
29(F)	+ 1.9	+ 4.4	+ 5.0	+ 6.7	+ 7.2	+ 5.2	- 1.0	- 6.3	-11.8	-14.5	- .32
139(M)	+ .5	- 2.1	-10.4	- 2.4	+ 1.6	+ 4.7	+ 6.7	+ 4.5	+ 5.6	+ 7.1	+ 1.58
41(F)	+ 1.8	+ 3.8	+ 5.1	+ 4.8	+ 6.7	+ 8.0	+10.3	+ 9.6	+ 7.7	+ 6.9	+ 6.47
WTD. AVE.	+ 1.68	+ 2.70	+ 1.54	+ 4.74	+ 5.22	+ 5.44	+ 4.72	+ 2.38	+ .28	- 1.04	+ 2.77
LEFT EAR TESTS:											
Dishabituation Subgroup (D):											
125(M)	- 5.2	- 6.6	- 2.8	- 2.9	- 1.1	- 8.6	-12.7	-17.2	-15.8	- 7.8	- 8.07
127(M)	+ 2.0	- 1.1	- 5.0	- 9.4	-11.8	- 9.5	- 2.6	0	- .3	- 1.4	- 3.91
25(F)	+ 1.6	+ 4.2	+ 5.0	+ 6.2	+ 1.0	-11.2	- 9.9	-12.0	- 2.7	+ .7	- 1.71
29(F)	+ .1	- .4	- 1.8	- 2.8	- 2.3	- 1.5	- 1.8	- 1.8	- 1.4	- 2.1	- 1.58
129(M)	- 4.6	- 7.5	-16.8	-24.1	-26.4	- 1.8	-10.3	- 3.1	- 1.7	- 5.7	-11.82
139(M)	- 5.4	- 4.5	- 4.5	- 6.1	- 7.3	- 7.9	- 7.5	-10.6	-17.9	-18.2	- 8.99
WTD. AVE.	- 2.07	- 2.43	- 3.92	- 6.10	- 7.67	- 8.97	- 6.92	- 6.50	- 4.87	- 4.13	- 5.36
Nondishabituation Subgroup (N):											
12(F)	+ 1.2	- .1	+ 1.5	+ 2.4	+ 1.9	+ 2.3	- 1.4	- 5.8	-11.9	-12.6	- 2.25
121(M)	+ 1.2	+ 2.9	+ 4.8	+ 5.9	+ 4.6	+ 6.3	+ 5.8	+ 3.7	+ 4.9	+ 5.2	+ 4.58
26(F)	+ 2.6	+ 3.2	+ 4.4	+ 4.2	+ 4.1	+ 5.5	+ 6.8	+ 7.1	+ 7.5	+ 5.8	+ 5.13
116(M)	+ 2.6	+ .8	+ 4.2	+ 4.4	- 1.0	+ 1.8	+ 1.2	+ 2.2	+ 3.3	+ 2.8	+ 2.23
41(F)	+ 2.0	+ 6.0	+ 5.9	+ .3	- .1	- .7	- 4.5	- 3.2	+ 2.6	+ 6.3	+ 1.46
132(M)	+ 2.2	+ 2.3	+ 2.0	+ .8	+ 2.1	+ 3.3	+ .7	+ .5	+ .3	+ 1.2	+ 1.54
WTD. AVE.	+ 1.97	+ 2.52	+ 3.80	+ 3.00	+ 1.93	+ 3.08	+ 1.43	+ .75	+ 1.12	+ 1.47	+ 2.11

[a] - Rather than simple arithmetic averages, these are the weighted averages calculated by the BALANOVA computer program for the unequal cell-size analysis of variance.

[b] - This test trial (10) deceleration was smaller than the trial 9 deceleration shown by this subject during the right ear consonant test; it does not support dishabituation.

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