THE RELATIONSHIP OF SPEECH-SOUND DISCRIMINATION TO THE DEVELOPMENT OF EAR ASYMMETRIES IN GRADE-SCHOOL CHILDREN

by

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Abstract

The relationship between ear asymmetry and speech-sound discrimination performance was examined for 364 Ss from ages 7-8, 9-10, and 11-12. Subjects were administered the Goldman-Fristoe-Woodcock Test of Auditory Discrimination and a single-pair-per-trial dichotic recognition task. The dichotic stimuli consisted of CVC nonsense syllables differing in medial vowel or initial stop consonant. For analysis of the dichotic recognition scores, a 3x3x2x2 between-within-subjects analysis of variance design was used, the between factors being age and level of discrimination ability, and the within factors being type of stimulus material and ear of presentation.

Both speech-sound discrimination and ear asymmetry were found to increase with age. Increases in left-ear advantage for vowel-varied material with increases in asymmetry was found to be due to decreasing right-ear recognition of vowel-varied stimuli. These results were discussed in terms of a unilateral dominance specific for speech as opposed to a bilateral dominance for both speech and nonspeech material. Therefore the common assumption of a specialization in the right hemisphere for functions involved in left-ear advantages is considered to be inaccurate.

In general, a positive relationship was found between the degree of ear asymmetry and speech-sound discrimination ability. To describe the relationship more adequately however, it was necessary to take into account the direction of ear asymmetry obtained for vowel-varied material. This asymmetry-direction factor was interpreted as reflecting the ability of subjects to use the nonencoded attributes of the speech signal. Inferior functioning with respect to this factor was found to result in a marked decrement in speech-sound discrimination performance and in a negative relationship between ear asymmetry and speech-sound discrimination. The influence of this factor was more evident in the younger age groups than it was in the 11-12 age group. The implications of the results were discussed with reference to the reading process and the development of remedial reading programs.

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CHAPTER I

LATERALITY AND HEMISPHERIC RELATIONS

The primary purpose of this investigation was to explore the nature of the relationship between the lateralization of language processes in the cerebral hemispheres and the ability to discriminate speech sounds. A secondary purpose was to test the appropriateness of the assumption that superiority of lateral response reflects hemispheric specialization for the function involved. This assumption is prevalent in the literature dealing with laterality, despite suggestive evidence to the contrary.

Although the human brain appears to be bilaterally symmetrical, the two hemispheres actually differ significantly in function. In 1836, Dax (see Critchley, 1964) introduced the idea of cerebral "dominance" as reflecting hemispheric asymmetry in the mediation of speech. If one hemisphere is dominant in language function, it would be expected that this asymmetry would be related in some way to such language-based skills as reading, writing, and speaking. Interest in the relationship of these abilities to cerebral dominance stems largely from the work of Orton (1937), and is being pursued more recently by such researchers as Bakker and Satz (1970), Critchley (1970), Delacato (1966), and Zangwill (1962). Generations of research on this topic has led to a massive body of

confusing and conflicting literature. In thorough reviews of the early literature, Johnson (1955) and Vernon (1957) concluded that if there is a relationship between cerebral dominance and language abilities, it is extremely obscure. More recent investigators have only added to the confusion concerning the topic — some finding evidence of a relationship (e.g., Cohen, 1969; Hunter & Johnson, 1971), and some not (e.g., Fagan-Dubin, 1974; Sabatino & Becker, 1971).

The conflicting results of studies conducted in an attempt to relate hemispheric laterality for language to language-dependent abilities may, in part, reflect the methodological difficulties and questionable assumptions associated with the assessment of cerebral dominance for speech. As this assessment is central to the present investigation, a major portion of this chapter is devoted to a discussion of this problem. A second problem with the research is associated with the tendency of researchers to treat complex abilities as singular variables and specific processes as global phenomena. Thus, even though an ability such as reading is a complex skill requiring the development of several processes and involving a multude of diverse interrelated factors, investigators have tended to treat reading as a singular variable represented by a single score. And, even though cerebral dominance for language most likely involves the lateralization and specialization of some very specific

processes, these processes have been generalized in terms of a global language dominance phenomenon. These generalizations are disadvantageous for research, as they tend to mask any meaningful and significant relationships there may be between cerebral dominance for speech and processes integral to the language-based skills.

If a positive relationship does exist between cerebral dominance for language and language abilities, this relationship would be most evident in the case of a language skill involving tasks that are closely associated with the specific processes integral to the lateralization phenomenon. This is the rationale followed in the present investigation. A discussion is included in the present chapter of the evidence concerning the specific processes involved in the lateralization of language processes and the resulting rationale for relating speech-sound discrimination to cerebral dominance.

The Problem of Determining Cerebral Dominance

A basic problem throughout the research has been the development of appropriate and reliable techniques for the measurement of hemispheric asymmetry for language. Most of the laterality research has been done with the assumption that handedness or "eyedness" is a reliable indicator of cerebral dominance for language and that a person who is not strongly unilateral in hand, eye, and foot preference is less advanced in terms of neural development than are

those whose lateral preferences are established.

Assessing Lateral Preferences

Lateral preference, or lateral dominance as it is most commonly referred to in the literature, is the tendency to use (or prefer to use) one limb, or one eye, more skillfully than the other. The determination of lateral preference is a far more complicated matter than is generally realized. Although appearing to be a dichotomous variable, assessed lateral preference is frequently discrepant with self-classification of handedness (Satz, Achenbach & Fennel, 1967). One of the difficulties is that hand preference is not reliably established until at least nine or ten years of age (Belmont & Birch, 1963; Critchley, 1970). Yet by far the majority of the studies using handedness as an indication of cerebral dominance have involved grade-school children as subjects.

A second difficulty is the diversity of measures used — measures that differ widely in physiological validity. Some entail motor skills which may be ordained by convention such as the manipulation of the fork and spoon, while other tests rely on supposedly more "natural" tasks. If a differentiation is made between "learned" (e.g., writing) and "unlearned" (e.g., hand clasping, finger feeding) responses, then handedness is found to be more consistent for learned than for unlearned activities (Hildreth, 1950). The correlations

between the two measures are quite insignificant (Bannatyne & Wichiarojote, 1969). It seems probable that the frequently reported variability or "weakness" of lateral expression in left-handed subjects could at least partially be accounted for by a poor understanding of the difference between learned and unlearned handedness.

Assessment problems also exist with respect to other modalities. According to Critchley (1970), young subjects normally show a discrepancy between the two lower limbs as regards lateral preferences for kicking and hopping. Regarding ocular laterality, further assesment complications derive from the fact that each eye is represented on an approximately equal bihemispheric basis. Eye dominance is variously reported in the literature in terms of the superior visual field, sighting preference, or acuity dominance. Bettman, Stern, Whitsell, and Goffman (1967) have demonstrated that the sighting eye is not the controlling eye for about half of normal subjects and that each of these measures is inconsistent with handedness for about one-third of the normal population. This kind of inconsistency across modalities has also been reported by Berman (1971), who intercorrelated modality measurements taken from some 30 different laterality tasks. Therefore, it would appear that most laterality tests do no more than inadequately measure a complex set of heterogeneous variables, failing to support the notion concerning a unitary process

or dimension underlying all manifestations of laterality.

Relating Lateral Preferences to Cerebral Dominance

The implicit assumption underlying the investigations relating handedness to language skills is that lateral preference is a reliable indicator of hemispheric dominance for speech. This assumption has remained despite the lack of direct evidence that handedness is related to organization of the cerebral hemispheres and despite an overwhelming amount of evidence indicating that there is no absolute correspondence between these peripheral measures and hemispheric asymmetries for speech.

One line of evidence indicating the incorrectness of assuming a direct and necessary relationship between manual preference and cerebral lateralization of language function is the investigations demonstrating that left cerebral dominance for speech is much more general than right handedness and right cerebral dominance is much less frequent than left handedness. These studies have been done primarily with epileptics and brain-damaged subjects. Using the Wada Sodium Amytal Test, Milner, Branch and Rasmussen (1964) found disturbances of language to be produced by the intracarotid injection of sodium amytal on the right side in only 17 of 117 left-handed subjects. Moreover, Milner and her colleagues emphasize that in these 17 cases the language disturbances were slight. Clinical studies of

aphasics with confirmed lesions (Luria, 1966; Hecaen & Sauguet, 1971; Penfield & Roberts, 1959) have demonstrated that, regardless of peripheral lateral preference, the speech of most individuals is mediated by the left cerebral hemisphere.

There is some evidence indicating that a relationship between peripheral lateral preference and hemispheric dominance for speech may hold only in cases in which laterality has been altered by disease. Satz (1972) has put forward an explanatory model with supporting evidence to account for the increased incidence of manifest left handedness in such clinical populations as epileptics, mental retardates, and disabled learners. His model is based on the estimation that left handedness occurs in eight per cent of the normal population and on the assumption that the side of a potential brain lesion occurs randomly in nature. Consequently, if studies of learning-disabled children are carried out in medical settings where the incidence of brain damage is higher than normal, then the chances of selecting a pathological left hander should also increase. This would spuriously increase the chance of finding a relationship between handedness and specific learning disability. The same questions would apply to the studies concerning the relationship between lateral preference and cerebral dominance for speech, since the majority of investigations have been based on brain-injured patients

who are epileptic. Thus Satz would view the assessed relationship between peripheral measures of laterality and cerebral dominance for speech as an artifact of sampling procedures.

Evidence would seem to indicate that in the absence of pathological alteration, peripheral lateral preference in humans is not related to hemispheric dominance for language. It would appear that lateral preference varies from function to function, and regarding handedness, that both left- and right-handed individuals demonstrate a decided left-hemisphere dominance for speech.

Alternate Measures

Assessing hemispheric dominance for speech has been a perplexing problem for investigators. Aside from the peripheral measures of laterality discussed above, most of the knowledge of cerebral representation for speech has come from patients who, as a result of brain pathology, were aphasic or were candidates for neurosurgery. Under these circumstances, it has been possible to determine the hemisphere dominant for speech. The procedure has obvious limitations for application in systematic investigations of cerebral speech dominance and its relationship to various other phenomena.

In recent years, however, two other experimental procedures have been developed: the Wada intracarotid-artery sodium amytal

test of speech given to candidates for neurosurgery (Wada, 1949), and the dichotic auditory stimulation technique. Although the Wada test is precise, it is not feasible to apply the test to subjects in the general population because of the risk associated with administration.

The dichotic auditory stimulation technique provides an alternative, though indirect, method of determining cerebral lateralization for speech. "Dichotic" refers to the simultaneous application of two different stimuli, one to each ear. In general, it has been found that under conditions of dichotic stimulation, an ear preference is typically shown in the recognition and recall of certain kinds of auditory stimuli.

Ear Asymmetry and Cerebral Dominance

The evidence relating ear asymmetry to hemispheric asymmetry for speech comes primarily from two sources: the correspondence of the results with other laterality measures; and from research exploring the conditions necessary to produce ear asymmetry.

Correspondence to other Laterality Measures

The comparison of dichotic stimulation results to those of the Wada sodium amytal test constitutes fairly compelling evidence of a relationship between ear asymmetry and cerebral dominance for language (Kimura, 1961a). Of 120 epileptic patients previously

administered the sodium amytal test, a group of 107 patients found to be left-hemisphere dominant for language produced averages of 86.5% and 79.8% correct responses for digits presented to the right and left ear respectively. But a group of 13 patients who, according to the Wada test, were right-hemisphere dominant for language were 88.5% accurate on left-ear stimuli and only 78.0% accurate on right-ear stimuli. Kimura presents analyses which indicate that this asymmetry in the direction of ear advantages obtained from subjects with speech represented in the left hemisphere versus the right hemisphere is independent of the location of the patient's epileptogenic focus.

If language lateralization is independent from peripheral lateralization as has been suggested, one line of indirect evidence relating ear asymmetry to hemispheric asymmetry for speech would be to demonstrate the independence of ear asymmetry from measures of peripheral laterality. Unfortunately, the relevant data are not as unequivocal as would be desired.

Several studies are available that involve a direct comparison of dichotic listening performance for right-handed versus left-handed subjects. Some of these studies have demonstrated that while right-handed subjects show right-ear superiority for verbal material, left-handed subjects show no consistent ear preference

(Satz, Achenbach & Fennel, 1967; Bryden, 1965; Zurif & Bryden, 1969). The stringently chosen left-handed subjects of Knox and Boone (1970) demonstrated a left-ear superiority for verbal material. Other investigations have demonstrated the same pattern of ear asymmetry for left-handed and right-handed subjects on both verbal and nonverbal tasks, although the magnitude of the asymmetry is not quite as marked in left-handed subjects as it is in right-handed subjects (Curry, 1967; Curry & Rutherford, 1967).

It has been argued (Inglis, 1965; Inglis & Sykes, 1967) that the peripheral laterality variable, order of report, is a much more significant source of variation in dichotic listening performance than is cerebral dominance for language. Inglis has demonstrated a response-bias for starting with the right ear in the recall of verbal material and a tendency for being more accurate on the first material recalled.

A more recent investigation into the effect of memory load on the right-ear advantage effect was undertaken by Yeni-Komshian, Gordon and Sherman (1973). A dichotic triad paradigm was used as in the studies reported above, but the time interval between stimulus presentation and response was varied between 5 and 15 seconds. With increasing delay times, the number of correct responses for the left-ear stimuli continued to decrease, while the number of

correct responses for the right-ear stimuli either levelled off or showed an increase. When the memory load was reduced by providing the subject with a list of all the stimuli, the right-ear effect was reduced due to an increase in the accuracy of the left-ear scores. These findings suggest that the right-ear advantage, as it is measured by traditional recall-type dichotic tests using multiple pairs per trial, is influenced by laterality factors other than perceptual asymmetry.

These extraneous laterality factors can be reduced in two ways: (1) by controlling for order of report in either the recall or the scoring; and (2) by using a simple one-pair-per-trial recognition paradigm. Fortunately, data are available from studies in which both these methods have been used to investigate the problematic relationship of peripheral laterality and dichotic listening performance. Reanalyzing the data by controlling for order of report, Zurif and Bryden (1969) demonstrated a significant right-ear effect for left-handed subjects, and Bryden (1970) found that left-handed subjects were just as likely to be right-ear dominant as were right-handed subjects. Thus, controlling for order of report factors reduced the differences previously found between right-handed and left-handed subjects.

Knox and Boone (1970) used both a multiple-pair-per-trial

dichotic digits test and a single-pair-per-trial dichotic words test to compare strongly lateralized left-handed subjects with right-handed subjects. Their findings of significant differences between the performance of right- versus left-handed subjects were evident only in the case of the dichotic-digits task. No difference between groups was evident with the simple one-pair-per-trial dichotic word task. These findings were confirmed by Dee (1971), who also found the pattern of laterality to be identical for strongly lateralized right-handed and left-handed subjects with one-pair-per-trial verbal and nonverbal tasks.

Additional evidence of the independence of ear laterality measures as obtained through one-pair-per-trial dichotic listening tasks and peripheral measures of laterality comes from two studies specifically designed to test the relationship between traditional measures of laterality as assessed by the Harris Test of Lateral Dominance and ear asymmetry (Sommers & Taylor, 1972; Sommers, Moore, Brady & Jackson, 1973). Subjects' scores on the Harris test were based upon consistency of laterality. Correlational analysis based on the Spearman rho coefficient indicated that dichotic performance was not significantly related to the traditional indices of laterality. Thus the evidence suggests an independence of ear asymmetry scores as measured by single-pair dichotic listening

tasks and the peripheral measures of laterality commonly used to assess cerebral dominance.

Ear Asymmetries and Speech Processing

Most pertinent to the question of the relationship of ear lateralities to hemispheric asymmetry for speech is the evidence concerning the conditions that are required to produce ear asymmetry effects in dichotic stimulation. This evidence also provides the rationale for hypothesizing a direct relationship between the magnitude of ear asymmetry and speech-sound discrimination ability.

Kimura (1961b) was apparently the first to relate ear laterality effects in dichotic stimulation tasks to hemispheric asymmetry. Using a dichotic-digits task, she found that subjects reported digits presented to the right ear more accurately than they did digits presented to the left ear. When other stimuli such as musical melodies were used (Kimura 1964, 1967), an apparent left-ear advantage was obtained. Thus, Kimura postulated hemispheric dichotomy for the processing of verbal and nonverbal stimuli — verbal stimuli being processed primarily by the left hemisphere and nonverbal stimuli by the right hemisphere.

Kimura based her explanation of the reversal in directional relationship between ear asymmetry and hemispheric asymmetry on

an hypothesized superiority of the contralateral over the ipsilateral afferent pathway. This superiority was based partially on the supposed greater number of contralateral neurons. Although neurophysiological investigation has failed to demonstrate that the contralateral pathway is superior anatomically, there is evidence concerning its functional prepotency in signal output (Thompson, 1967). This contralateral prepotency seems to be increased in tasks involving simultaneous stimulus competition, such as that involved in dichotic listening (Sparks, Goodglass, & Nickel, 1970).

There is a great deal of evidence to support the notion that the presence of linguistic material is necessary to produce asymmetries in favor of the right ear. The right-ear advantage has been obtained with a wide variety of speech stimuli: with digits (Bartz, Satz, Fennel & Lally, 1967; Broadbent & Gregory, 1964; Bryden, 1963, 1967, 1970; Corballis, 1969; Dirks, 1964; Kimura, 1961b, 1963; Knox & Boone, 1970; Knox & Kimura, 1970; Satz & Friel, 1973; Satz, Rardin & Ross, 1971; Sommers, Moore, Brady & Jackson, 1973; Sommers & Taylor, 1972; Witelson & Rabinovitch, 1972); with monosyllabic words (Borkowski, Spreen & Stutz, 1965; Curry, 1967; Curry & Rutherford, 1967; Jones & Spreen, 1967; Knox & Kimura, 1970; Sommer, Moore, Brady & Jackson, 1973; Sommers & Taylor, 1972); with multisyllabic words (Bartz, Satz, Fennel

& Lally, 1967); with continuous speech (Oxbury, Oxbury & Gardiner, 1966; Treisman & Geffen, 1967); with inverted speech (Kimura & Folb, 1968); and with nonsense syllables (Berlin, Hughes, Lowe-Bell, & Berlin, 1974; Berlin, Lowe-Bell, Cullen, Thompson & Loovis, 1973; Curry, 1967; Curry & Rutherford, 1967; Darwin, 1969a, 1971; Day & Vigorito, 1973; Haggard, 1971; Haggard & Parkinson, 1971; Kimura, 1967; Kirstein & Shankweiler, 1969; Shankweiler & Studdert-Kennedy, 1967; Spellacy & Blumstein, 1970; Studdert-Kennedy & Shankweiler, 1970). On the other hand, dichotic listening studies in which nonspeech stimuli were used have consistently failed to produce a right-ear advantage. This has been demonstrated using musical stimuli (Darwin, 1969b; Gordon, 1970; Kimura, 1964, 1967; Spellacy, 1970; Spreen, Spellacy & Reid, 1970), sonar signals (Chaney & Webster, 1966), environmental sounds (Curry, 1967; Kimura & Knox, 1970; Spellacy & Blumstein, 1970) and clicks (Murphy & Venables, 1969). On the basis of the above investigations, the evidence seems to indicate that the presence of linguistic material is a necessary condition for the production of asymmetry in favor of the right ear. Of greater significance to the present study is the research defining the particular attributes of speech that are associated with the observed asymmetries. And it is also this area of research that most directly indicates a relationship between ear

laterality and perceptual asymmetries in speech and provides the rationale for relating speech-sound discrimination to these phenomena.

The central investigation in this line of research was undertaken by Shankweiler and Studdert-Kennedy (1967). They tested their subjects with consonants and steady-state vowels separately and found a significant right-ear advantage for consonants but none for vowels, even though vowels would qualify as linguistic stimuli. Consonants and vowels differ in their degree of encodedness — an attribute of essential importance in the perception of speech (Liberman, Cooper, Shankweiler & Studdert-Kennedy, 1967). To be more highly encoded, in acoustic terms, means to undergo more restructuring as a function of neighboring phenomes. Encoding is not defined by any single acoustical correlate. Rather, encoding results from the movement of an articulator from one position to another. Thus the amount of encoding tends to be high where there is articulatory and, hence, acoustical change. These acoustical changes are rapid variations in the frequency spectrum known as "formant transitions". If these formant transitions are deleted experimentally, speech becomes unintelligible (Cole & Scott, 1973). Thus, these encoded attributes, especially in the form of formant transitions, are necessary to the perception of speech.

As phoneme categories differ in their degree of encodedness, it seems logical that, if the phenomenon of ear laterality is related to speech perception, then the magnitude of ear asymmetry should parallel the degree of encodedness of the material. Stop consonants are the most highly encoded, vowels the least encoded, with liquids in between. Regarding vowels, natural vowels embedded in a consonant framework are more encoded than are isolated vowels, with steady-state vowels representing the nonencoded end of the encodedness continuum (Liberman et al., 1967).

The evidence appears to support the hypothesis that there is a relationship between degree of encodedness and magnitude of ear asymmetry. While studies have shown consistent right-ear advantage for consonants (Berlin et al., 1973; Berlin et al., 1974; Cutting, 1973; Darwin, 1969a, 1971; Day & Vigorito, 1973; Haggard, 1971; Haggard & Parkinson, 1971; Kirstein & Shankweiler, 1970), investigators have been unable to demonstrate a right-ear advantage using isolated steady-state vowels (Darwin, 1969a; Kirstein & Shankweiler, 1969; Shankweiler & Studdert-Kennedy, 1967). However, right-ear advantages have been obtained using natural vowels embedded in a consonental frame (Goodglass, 1973; Haggard, 1971; Spellacy & Blumstein, 1970; Studdert-Kennedy & Shankweiler, 1970; Weiss & House, 1971). Directly comparing stop consonants, liquids, and

vowels for differences in magnitude of ear asymmetry, researchers have attained the greatest magnitude for consonants and the least for vowels (Cutting, 1973; Day & Vigorito, 1973).

Another line of support for the importance of transitional formants in the production of ear asymmetries comes from a study by Darwin (1971) concerning the perception of fricatives. There are two main cues which contribute to the perception of fricatives. The first, and perceptually the most significant cue, is the spectral peak of the friction itself. A secondary cue is the formant transition to adjacent vowels. The study included the four stimulus conditions of friction alone, friction plus steady-state vowel, friction plus appropriate formant transitions, and the appropriate formant transitions plus vowel, minus the friction. Although fricatives synthesized from friction alone — without the formant transitions — were clearly identifiable, only the two conditions which included the formant transition showed a right-ear advantage.

A rather novel experiment by Halperin, Nachshon and Carmon (1973) also emphasized the importance of transitional cues. These investigators varied the number of stimulus transitions within sound sequences from zero to two and found that the number of subjects showing a right-ear advantage increased significantly with the

complexity of the sequential transition.

The evidence from the above investigations implies the presence of a lateralized speech processing mechanism that is specialized in the perception of the encoded attributes of the stimuli. It would be logical to hypothesize that those abilities which rely most heavily on this linguistic mechanism are related closely to its development or specialization. This is the rationale for relating speech-sound discrimination to ear asymmetry. Speech-sound discrimination involves the ability to select and discriminate among sounds differing in acoustical features. In a comparison of the relative importance of the differing acoustical attributes, Cole and Scott (1973) have found the transitional formants to be essential for effective discrimination of speech. As the perception of these encoded attributes is integral to the production of ear asymmetries and presumably, therefore, to the lateralization of language processes, a positive relationship between the two phenomena would seem to be highly probable. If the inferences from the data are plausible, one would expect that the greater the level of specialization (or the more developed the linguistic mechanism), the greater the magnitude of ear asymmetry and the higher the level of discrimination ability for speech sounds.

Nature of Hemispheric Relations

Although the presence of encoded attributes appears to be a necessary condition for the production of ear asymmetries, another line of research indicates that the presence of these attributes is not a sufficient condition for ear asymmetry effects. The importance of this research for the present investigation lies primarily in implications regarding the nature of hemispheric perceptual asymmetries, and more specifically, the appropriateness of the assumption linking superiority of response to hemispheric specialization.

Several investigators have found evidence of a left-ear advantage for material containing encoded cues. Although consonants have consistently yielded a right-ear advantage, Muraski and Sharf (1973) have demonstrated that if consonants are labelled as noises of varying pitch, subjects identify them more often with the left ear than with the right. When the consonants were labelled as speech sounds, the characteristic right-ear advantage was obtained. Other investigations have also demonstrated a left-ear advantage when subjects were attending to nonverbal properties (intonation, pitch or emotional tone) of dichotic verbal input (Blumstein & Cooper, 1974; Darwin, 1969b; Haggard & Parkinson, 1971) or when subjects were identifying vowel-varied CVC nonsense syllables in a nonverbal context (Neufeld, 1971; Spellacy & Blumstein, 1970). The evidence suggests that a right-ear

advantage depends upon both the presence of some encoded acoustical cue and a task or "attentional set" that makes that encoded property relevant. On the other hand, a left-ear advantage for material containing both encoded and nonencoded cues requires a task or 'set' that makes the nonencoded cues the more salient attributes of the stimulus material.

The specific nature of the left-ear advantage demonstrated by these investigations is much less understood. As was mentioned above, Kimura (1967), following the common practice in the laterality research, proposed that the greater left-ear scores for certain nonverbal attributes reflects right-hemisphere specialization for nonverbal functions. This notion will be referred to here as Kimura's bilateral dominance model. According to this model the left hemisphere is specialized for verbal processing and the right hemisphere for nonverbal processing. That is, it implies that there is a perceptual mechanism in the right hemisphere that is specialized for particular stimulus properties characteristic of certain nonverbal sounds. From this view the right hemisphere would be expected to be superior in the processing of the nonencoded cues of auditory stimuli, just as the left hemisphere is superior in the processing of encoded cues. Although too few experiments concerning the left-ear advantage effect have been conducted to enable an evaluation of such a hypothesis, it

has been the popularly espoused notion throughout the dichotic stimulation literature.

There is evidence which suggests that this assumption of a right-hemisphere superiority for nonencoded attributes is not appropriate and that Kimura's bilateral dominance model does not provide an adequate interpretation of hemispheric relations. In a study by Spellacy and Blumstein (1970), the subjects' 'set' was manipulated by creating an expectation of hearing language sounds or an expectation of hearing nonlanguage sounds. The results showed that although a right-ear advantage for vowel-varied sounds was obtained in the language-expectation group and a left-ear advantage in the nonlanguage group, the recognition scores for the left ear were the same in the two conditions. Both ear differences resulted almost solely from fluctuation in right-ear performance, which presumably reflects left cerebral hemispheric function. In other words, the apparent left-ear advantage was due, not to enhanced left-ear performance, but to a decrement in recognition of sounds presented to the right ear. Thus, both the right- and left-ear advantages appear to be a function of left hemispheric specialization for speech. These data support a <u>unilateral dominance model</u> as opposed to Kimura's bilateral dominance model of hemispheric relations.

This phenomenon was further explored by Neufeld (1971) with a

developmental paradigm in which stimuli associated with both right- and left-ear advantages were used. The recognition scores in a developmental paradigm are confounded with the influence of age. However, there was tentative evidence that an increase in ear asymmetry for left-ear advantage material was due primarily to a decrease in right-ear recognition scores. As the data were contaminated to some extent by the effects of age, a definitive statistical analysis of the significance of this result was not possible.

Evidence for a unilateral dominance model also comes from a study of auditory evoked potentials during speech perception (Wood, Goff & Day, 1971). Neural activity evoked by the same consonant-vowel syllable was compared during the performance of two auditory identification tasks. One task required identification of the stop consonant and thus involved the encoded attributes as the more salient cues. The other task required identification of the fundamental frequency of the CV syllables — a nonencoded attribute of the stimulus material. Evoked potentials from the right hemisphere were identical for both tasks. However, statistically significant differences in evoked potentials were observed in the case of the left hemisphere. There was an increase in activity when the encoded attributes were attended to and a decrease in activity when the nonencoded attributes were attended to. Thus, any superiority in right-hemisphere

activity was a result of differences in left-hemisphere only.

These studies provide strong support for the unilateral dominance model as opposed to the bilateral dominance model of hemispheric relations. Both the left- and right-ear advantages reported in the studies discussed would appear to be a result of left-hemisphere function only. These results indicate that the prevalent practice of inferring specialized function for lateral advantages may not be appropriate in all cases. It would seem to be more parsimonious to hypothesize a decrement in right-ear performance when encoded attributes are not utilized than to hypothesize a specialized processor in the right hemisphere for nonverbal sounds. One of the secondary purposes of the present study was to address this question more directly than has been done in the previous investigations.

CHAPTER II

EAR ASYMMETRY AND SPEECH-SOUND DISCRIMINATION

Unfortunately, there are no available studies directly relating speech-sound discrimination to ear asymmetry as measured by dichotic stimulation tasks. Several investigations are available, however, in which the relationship between ear asymmetry and reading has been explored. Depending on the relationship of speech-sound discrimination to reading, these investigations could provide indirect evidence concerning the present question. Thus the evidence relating speech-sound discrimination to reading will be discussed first.

Speech-Sound Discrimination and Reading

The basis for linking speech-sound discrimination to reading is both theoretical and empirical. Although reading would appear to be primarily dependent on the visual modality, several recent theorists regard reading as being primarily an auditory-based skill (Becker, 1971; Rosner & Simon, 1971; Witken, 1971; and Zigmond, 1969). There is a mounting body of evidence to substantiate this claim. Golden and Steiner (1969) and Kirby, Lyle and Amble (1972) found that scores on the auditory subtests of the Illinois Test of Psycholinguistic abilities are significantly related to reading performance,

while scores on the visual sub-tests are not. Reviewing the major investigations on the relationship of visual perception and reading problems, Benton (1962) concluded that the visual modality is of relatively little significance and that reading problems are most likely to be associated with dysfunction in some aspect of auditory functioning.

One line of indirect evidence of the importance of auditory functions with respect to reading comes from studies with blind subjects. Brodlie and Burke (1971) observed 200 blind children to study perceptual problems that the children had in learning to read Braille. They found error patterns analagous to those found in sighted children with reading difficulties in about 15% of the group. These results would seem to indicate that reading problems are somewhat independent from the visual modality. Although most investigators have considered reversals in reading to be a problem in visual perception, there is evidence indicating the importance of the linguistic context of the letters as a determinant of confusions in letter orientation, the most frequent errors tending to differ from the correct consonant in one phonetic feature (Liberman, Shankweiler, Orlander, Harris and Berti, 1971).

Levine and Fuller (1972) compared the mean scores of 44 children, aged 8 to 13, and with a reading deficit of one or more years, to

appropriate norms for the population on 38 psychoneurological, psychological and educational test variables. The poor readers performed most poorly on items that dealt with the auditory process but functioned normally on items dealing with the visual modality. The one variable that best discriminated among ability groups at all ages tested was the speech-sound discrimination variable.

In a study by Flynn and Byrne (1970), 39 third-grade children (19 of whom were advanced by at least one year in reading and 20 of whom were retarded by at least one year in reading) were tested on a one-hour battery of auditory tests. Significant differences were found between the performance of the groups on the auditory tests, with highly significant differences occurring on tests requiring discriminatory judgments between speech sounds.

The relationship between speech-sound discrimination and reading performance has also been supported by Blank (1968) with children of six years and of seven years and by Clark (1970) with children of eight years. And De Hirsch, Janksy and Langford (1966) found that poor speech discrimination at the ages of five and six was one of the best predictors of subsequent inability to learn to read normally.

Although the investigations to date have been relatively few in number, the evidence would seem to implicate speech-sound

discrimination as an integral developmental skill in reading performance. On the basis of this evidence, the studies relating ear asymmetry to reading are discussed.

Ear Asymmetry and Reading

Zurif and Carson (1970) demonstrated a tendency (though not a significant one) for 14 normal readers to report more digits presented to the right ear than to the left ear. In contrast, 14 poor readers did not show an ear preference as a group, demonstrating a greater variability in ear asymmetries. Reading performance was defined as being above or below the expected level as defined by the Gates Reading Test.

Bryden (1970) reported relative incidence of right-ear superioity rather than degree of asymmetry in good versus poor readers. The subjects were 90 children, 15 males and 15 females from each of Grades 2, 4, and 6. Subjects were administered the Gates-MacGinitie Reading Tests and the Otis Quick-Scoring Mental Ability Test, and classified as "good" or "poor" readers depending on whether the reading scores were higher than or lower than would be predicted on the basis of the intelligence scores. While both groups showed a greater incidence of right-ear asymmetry, good readers were more likely to demonstrate right-ear asymmetry than were poor readers, although the difference was not significant.

Using a more stringent definition of reading retardation, Sparrow and Satz (1970) studied 80 white male children between the ages of 9 and 12 from a suburban middle class school to determine the relationship between dichotic stimulation and reading skills. Half of the subjects in each age group were retarded readers who ranged from 20% to 61% below the appropriate reading level for their age, as measured by the Iowa Test of Basic Skills and Metropolitan Achievement Test. These were matched with subjects who had reading scores at or above the expected level for age, sex, social class, and Performance intelligence scores as assessed by the Wechsler Intelligence Scale for Children. Using a dichotic digits task, Sparrow and Satz found that recall was far superior for digits presented to the right ear for both groups, with no significant differences in degree of asymmetry being evident between groups. The groups did differ significantly with respect to incidence of right-ear superiority however, with normal readers showing an incidence of 92% and retarded readers an incidence of 72%.

In a fourth study, Satz, Rardin and Ross (1971) investigated the relationship of dichotic stimulation to reading ability using a small sample of 40 male children ages 7-8 and 11-12. Half of the subjects had reading performance scores which were below the norms for their grade. These subjects were matched with normal readers for

Performance intelligence scores, sex, race and age. Both groups demonstrated a right-ear superiority for the recall of digits at both age levels. However, the degree of superiority increased in the good readers to a greater extent than in the retarded readers. Significance levels however, were not reported.

The methodological inadequacies of these studies make it dificult to evaluate the tentative results obtained. In none of the studies reported were peripheral laterality factors such as order of report controlled for, and the sample sizes were, for the most part, quite small. As with other studies involving the reading process, reading performance was defined variably from study to study.

Despite these limitations, the results do offer tentative support for a relationship between ear asymmetry and reading ability, and by inference, speech-sound discrimination. In two of the studies there was evidence of trends toward a greater magnitude of ear asymmetry in good readers than in poor readers. In the other two studies, there was a greater incidence of right-ear superiority in groups of subjects with good reading performance than in groups of subjects with poor reading performance. These investigations highlight the problems that were discussed previously of using reading ability as a singular research variable, and they point out the need for research that is more focussed and direct in the investigation of the relationship

of speech lateralization to language skills.

CHAPTER III

THE PROBLEM

The primary purpose of the present study was to investigate the nature of the relationship between ear asymmetry and speech-sound discrimination. As speech-sound discrimination is a task that involves the sequential analysis and differentiation of encoded acoustical cues, performance on this task should presumably increase with the developing specialization of the speech processor in the left hemisphere. Thus higher levels of speech-sound discrimination schould be associated with greater magnitudes of ear asymmetry, while lower levels of speech-sound discrimination should be associated with a lesser degree of ear asymmetry.

The secondary purpose of the present study was to investigate the unilateral dominance hypothesis as an alternative to Kimura's bilateral dominance hypothesis. The primary expectation was that any apparent increase in the magnitude of a left-ear advantage would be due to a decrement in right-ear recognition rather than enhanced left-ear recognition. Greater magnitudes of asymmetry are expected to be associated with higher levels of speech-sound discrimination, and in the case of left-ear advantage material, a decrement in right-ear recognition. Combining the hypotheses would lead to the prediction that greater abilities in speech-sound discrimination should

be associated with poorer right-ear performance when the right ear is stimulated with left-ear advantage material.

A developmental paradigm was chosen with grade school children being used as subjects. Although most evidence seems to indicate the gradual development of language abilities through the grade school years, the developmental studies using dichotic stimulation tasks have been quite disparate in their findings. Several investigators have found the magnitude of ear asymmetry to be at its maximum about age five or six and to decrease in magnitude with age (Geffner & Hochberg, 1971; Kimura, 1963, 1967; Knox & Kimura, 1970; Nagafuchi, 1970) — a reversal of the expected developmental trend. The methodological inadequacies of these studies, however, would tend to reduce the usefulness of the results in making conclusions about hemispheric lateralization for speech.

These studies all involved the use of the multiple-pair-per-trial dichotic digits task that has been shown to be so sensitive to the order of report and channel capacity factors that were discussed above. A study by Inglis and Sykes (1967) indicates that in multiple-pairs-per-trial free recall procedures, these factors may have a greater influence upon the dichotic listening performance of children than upon that of adults. A study of Berlin, Hughes, Lowe-Bell, and Berlin (1974) demonstrated that the ability of children to recall more items

correctly increases with age. Combined with demonstrated order of report factors, this might lead to the decreasing ear asymmetry found in these investigations.

The investigations showing decreasing asymmetry with age are also at variance with neurological studies in which brain-damaged children were used as subjects. The clinical literature suggests that in the first years of life speech representation is bilateral, with language and speech becoming progressively and irreversibly lateralized to the left cerebral hemisphere, complete speech differentiation being achieved around puberty (Basser, 1962; Belmont & Birch, 1965; Benton, 1964; Kinsbourne & Warrington, 1963; Lenneberg, 1967). This deduction comes from evidence that during the elementary school years, the likelihood of right-hemispheric damage producing long-lasting aphasic disorders gradually decreases, while the likelihood of left-hemispheric damage producing long-lasting aphasic disorders gradually increases. Also, recent neuroanatomic studies have shown that those areas in the cerebral cortex critical for receptive language show relatively late ontogenetic development, often not maturing until late childhood (Geschwind, 1965, 1968). This time period would correspond to the results of the clinical literature with regard to the complete maturational development and cerebral polarization of speech.

A number of developmental investigations have achieved results more in line with the neurological findings. Bryden (1970), reporting the relative incidence rather than the magnitude of right-ear superiority, found that incidence of right-ear superiority increased with age in grade-school children. When the data from the Knox and Kimura (1970) and Geffner and Hochberg (1971) studies are re-evaluated for incidence, rather than magnitude of ear asymmetry, results similar to those of Bryden are obtained.

Neufeld (1971) and Berlin et al. (1974), using one-pair-per-trial paradigms, both demonstrated an increase in the magnitude of ear asymmetry with age in grade-school children, but this effect was significant only in the investigation by Neufeld (1971) in which a simple recognition paradigm was used. Berlin et al. (1974) used a verbal recall paradigm with the younger subjects and a written response paradigm with the older ones. A study by Clark, Knowles and Maclean (1970) has shown that items recalled second in a dichotic listening task are more accurately recalled when they are written than when they are spoken. If this effect is reliable, it would have tended to counteract the trend towards greater ear asymmetry with age, thus possibly leading to the insignificant results.

The above investigations highlight the importance of selecting the proper paradigm and procedures for dichotic stimulation. The

dichotic task chosen for the present study was the one-pair-per-trial recognition paradigm used previously in investigations by Neufeld (1971) and Spellacy and Blumstein (1970). This task meets the criterion of minimizing order of report factors while remaining sensitive enough to detect ear asymmetries in normal subjects. The task is simple enough to be understood by the youngest subjects to be tested, and thus does not require the administration of different instructions and procedures at different age levels. Also, the non-language set provides the data on left-ear advantage material that are necessary to evaluate the predictions concerning the unilateral dominance hypothesis.

The speech-sound discrimination task chosen was the Goldman-Fristoe-Woodcock Test of Auditory Discrimination (G.F.W.) (Goldman et al., 1970). One of the main criteria for selecting a test of speech-sound discrimination was its utility in studying normal development. Most speech-sound discrimination tests are constructed in such a way that a ceiling effect is present by the age of eight (Templin & Darley, 1964; Weiner, 1967; Wepman, 1958), and thus would not be of use in this developmental paradigm. The standardization data given for the G.F.W. task attest to its ability to discriminate among ages with normal subjects through the grade school years.

The test, together with standardization, reliability and validity data are described in detail in Goldman, et al. (1970).

Summary of Hypotheses

The primary hypothesis of the present investigation is that there is a positive relationship between the ability to discriminate between speech sounds and the magnitude of ear asymmetry in elementary school children. The rationale for this relationship was discussed in Chapter I, and the related empirical evidence was noted in Chapter II.

Related to this hypothesis is the prediction that speech-sound discrimination increases with age in grade school children. This prediction is based on evidence cited above regarding the development of language processes in children and on previous investigations with speech-sound discrimination (Goldman et al., 1970).

Regarding the direction of ear asymmetry, a right-ear advantage was predicted for the consonant-varied stimuli, and a left-ear advantage was predicted for the vowel-varied stimuli. The left-ear advantage for the vowel-varied stimuli would presumably be due to the presence of a non-language set created by the experimental stimuli being interspersed with dichotically presented music and sound effects, making the encoded attributes irrelevant to the identification task. A right-ear advantage was predicted for the

consonant-varied stimuli, as only the encoded attributes of a stop consonant are relevant to its identification (Liberman et al., 1967).

Of primary importance to the investigation are the hypotheses having to do with the nature of hemispheric relations regarding auditory perception. It is suggested that the apparent left-ear advantage for material not linguistically relevant is due not to increased perception associated with specialized right hemisphere auditory processing, as is the popularly held notion in the relevant literature, but rather results from a decrement in the perceptual processing in the left hemisphere as is suggested by Spellacy and Blumstein (1970) and Neufeld (1971). Thus, any increase in ear asymmetry with vowel-varied stimulus material should be due to a decrease in right-ear recognition, left-ear recognition remaining unchanged with increasing asymmetry.

For right-ear advantage material, it was hypothesized that increases in ear asymmetry should be the result of a simultaneous increase in right-ear recognition and decrease in left-ear recognition. This hypothesis is based on the premises that the right-ear effect is presumably due to specialized processing of encoded attributes in the left hemisphere and that right-hemisphere involvement in language functions decreases as left-hemisphere involvement increases. The latter premise is based primarily on evidence from clinical studies.

Combining the principal hypotheses leads to the predictions that with left-ear advantage stimulus material, higher discrimination performance should be associated with lower right-ear recognition, while left-ear scores should be unrelated to discrimination performance. With right-ear advantage stimulus material, speech-sound discrimination ability should be related in a positive direction to recognition of material presented to the right-ear and inversely to recognition of material presented to the left ear.

Regarding the relation of ear asymmetry with age, it would be consistent with the previous predictions of increased ability in speech-sound discrimination with age and a positive relationship between ear asymmetry and speech-sound discrimination that ear asymmetry should increase with age. As was discussed previously, this prediction is consistent with both the clinical literature and the developmental studies of Berlin et al., (1974), Bryden (1970) and Neufeld (1971).

In addition to the hypotheses directly related to the stated aims of the present study, two additional predictions were made on the basis of findings in previous speech discrimination studies and dichotic stimulation experiments. One prediction was that overall recognition performance would increase with age. This relationship between age and dichotic listening performance has been reported by Berlin et al. (1974), Bryden (1970), Geffen and Hochberg (1971),

Inglis and Sykes (1967), Kimura (1963, 1967) Knox and Kimura (1970), Nagafuchi (1970) and Neufeld (1971). It was also expected that there would be sex differences with reference to speech-sound discrimination ability in favor of females. This is based on investigations by Goldman et al. (1970).

In summary then, the present investigation was concerned with the following predictions:

1. An increase in the magnitude of ear-asymmetry with increasing levels of discrimination ability for speech sounds.

2. An increase in speech-sound discrimination with age.

3. An increase in ear asymmetry with age.

4. A right-ear advantage for consonant-varied stimuli.

5. A left-ear advantage for vowel-varied stimuli.

6. An increase in right-ear recognition with increasing levels of speech-sound discrimination performance for consonant-varied material.

7. A decrease in right-ear recognition with increasing levels of speech-sound discrimination performance for vowel-varied material.

8. A decrease in left-ear recognition with increasing levels of speech-sound discrimination performance for consonant-varied material.

9. An independance of left-ear recognition scores with speech-sound discrimination levels for vowel-varied material.

10. An increase in dichotic stimulation recognition performance with age.

11. A sex difference in favor of females in speech-sound discrimination performance.

CHAPTER IV

METHOD

Subjects

The Ss were 364 elementary school children in three age groups: 7 years, 5 months to 8 years, 5 months; 9 years, 5 months to 10 years, 5 months; and 11 years, 5 months to 12 years, 5 months. These ages corresponded to the normal ages for Grades 2, 4, and 6. Three schools were used. All three schools were in a suburban middle class community. Only Ss judged by their teachers to have no known auditory impairments were included in the study. Of the 364 Ss, four were excluded because of failure to follow instructions.

Procedure

The apparatus used to present the speech-sound discrimination stimuli and the dichotic stimuli consisted of a Sony TC 630 stereophonic tape-recorder, a six-jack stereophonic listening station, and six sets of padded stereophonic earphones (Sharpe Pro HA 660). The Ss were first administered the Training Procedure of the G.F.W. test. Prior to the training session, E spent a few minutes establishing rapport, and giving a brief explanation regarding the purpose of the experiment (i.e. "to see how we hear things"). The instructions were given as recommended in the testing manual (Goldman et al. 1970), with the addition of instructions to "please look carefully at

all four pictures each time before choosing." The purpose of the training procedure was to familiarize the Ss with the word-picture associations to be used during the discrimination task and to permit the E to establish the presence of these associations. Sixteen training plates with four pictures each were presented. The names of the pictures were presented twice during the training session, with instructions to the S to point to first one picture, then another picture each time. If the S did not point to the correct picture, the E indicated which picture was the correct one and used verbal and gestural aids to help the S associate the correct label with the picture. At the end of the training session Ss were retested for these associations. This procedure was necessary in only a couple of instances.

The speech-sound discrimination task and the dichotic stimulation task were administered by tape. A sound meter was used for calibrating the speech-sound discrimination tape to produce a 70 db SPL signal in the earphones. A calibration tone was provided on the G.F.W. prerecorded tape for this purpose. The signal of the dichotic stimulation tape was then matched in intensity to the speech-sound discrimination tape, although the technical difficulties in calibrating speech signals prevented the assurance of absolute equivalence. The intensities however were the same for all subjects.

The Ss were tested in groups, usually of five, each session

taking approximately 50 minutes, with a rest interval for the Ss between the discrimination and dichotic tasks as well as an interval half-way through the dichotic stimulation task. Individual desks were placed facing away from the tape recorder and in a semicircle to minimize distraction. The stimuli were monitored by E through a sixth set of earphones connected to the listening station.

Before the earphones were placed on the Ss, instructions were presented outlining the nature of the task and directing the S to mark an "X" on the yellow square by the right picture, being sure to listen carefully and to look at all four pictures each time. The Ss were instructed to turn the page as soon as they had marked their "X", so they would be ready for the next word.

The speech-sound discrimination task consisted of three training plates and 30 test plates. To ensure that all Ss had enough time to respond, the E paused the recorder momentarily between stimuli when it was required to do so. This procedure was necessary occasionally with the younger Ss. The speech-sound discrimination score for each S represented the number of correct responses out of a total of 30 items.

Following a rest interval of two to three minutes, instructions were presented to the Ss outlining the nature of the dichotic stimulation task. Special care was taken to orient the Ss to the response

sheet, and an attempt to reduce anxiety was made by assuring the Ss that the task was not difficult and that since "each person hears things a little differently", we were particularly interested in how each of them heard things. Tape recorded instructions reiterated the nature of the task and provided two examples as well as an opportunity for questions. Pilot procedural work emphasized the importance of allaying anxiety concerning the task and preceding the taped instructions with a verbalized version, especially with the younger Ss. With the use of this procedure, only four subjects had to be excluded for failure to follow instructions.

The auditory stimulation procedure consisted of 80 dichotic stimulus pairs presented one pair at a time. Each pair was presented twice to make a total of 160 presentations. Each dichotic stimulation was preceded by an indication of the trial number and was followed, after one second, with a diotic recognition foil (i.e., the same stimulus simultaneously at both ears). There was an interval of five seconds between the recognition stimulus and the onset of the next dichotic presentation. The Ss were instructed to respond by marking an "X" under "yes" on a prepared answer sheet if the recognition stimulus was the same as one of the members of the preceding dichotic pair, or under "no" if the recognition stimulus was different

from either of the members of the preceding dichotic pair. Thus a correct response for the right ear would be recorded if an S marked "yes" when the item member of the dichotic pair presented to the right ear was the same as the following recognition stimulus presented diotically. And a correct response for the left ear would be recorded if an S marked "yes" when the item member of the dichotic pair presented to the left ear was the same as the diotically presented recognition stimulus. The number of correctly recorded "yes" responses constituted an S's score for a particular ear on a specific type of stimulus material. To control for any channel differences arising from inequalities in the apparatus, half of the Ss in each cell had the earphone order reversed relative to the other half.

Stimulus Materials

The stimuli used in the G.F.W. speech-sound discrimination task were all monosyllabic in length and of a consonant-vowel-consonant or consonant-vowel form when spoken. Only items which would be in the recognition vocabulary of young children and which could be depicted in line drawings were included. Sixty-one such words and pictures were combined in various sets of four to provide the necessary training and testing materials. The stimuli differed in four distinctive features: voicing; stop; nasality; and place of articulation. Generally the three distractor words on each test plate were drawn

from the population of words that differed in only a simple distinctive feature. Limitation imposed by the vocabulary of young subjects and the need for pictoral representation did not make this practical in all cases. Wherever possible, distractor words were selected which represented only place-of-articulation differences, since place of articulation appears to be one of the most important distinctive features for speech-sound discrimination (Wickelgren, 1966). Superimposed on the stimuli was controlled background noise at nine decibels less than the signal. The background noise was obtained by recording environmental sound in a busy school cafeteria and amplitude-compressing it to produce a background noise of semi-intelligible real noise at a relatively constant amplitude.

The dichotic stimulation material was adapted from the investigations of Neufeld (1971) and Spellacy and Blumstein (1970). Two types of experimental stimuli were used. These were interspersed with the nonverbal nonexperimental stimuli that were included to produce a nonlanguage set. Twenty pairs of dichotic stimuli were CVC nonsense syllables that differed in initial consonant. The initial consonants varied with the six stop-consonants /p, t, k, b, c, g/. The other twenty pairs of dichotic stimuli were CVC nonsense syllables that differed in the medial vowel. The vowels varied were /i, e, a, ə, o, u/.

In addition to the experimental stimuli, twenty pairs of dichotic stimuli were exerpts of sung melodies, made up of melodic repetitions of the CV syllable /da/. The remaining twenty dichotic pairs were human imitations of animal and machine sounds. All sounds were created by the same voice, and no deviation from simultaneity of onset was perceptible to E.

In the recording of the stimulus material, the randomized series of 80 dichotic pairs was repeated with channels reversed so that a member of a dichotic pair that would be presented to the left ear in the first half of the experiment would be presented to the right ear in the second half. Also, recognition foils were assigned randomly to dichotic pairs but with the restriction that, if a pair was followed by a neutral foil in the first half (i.e. requiring a "no" response), it would be followed by a positive foil in the second half and vice versa. A further restriction was that 25% of the recognition stimuli were identical with right-ear stimuli, and 25% were identical with the left-ear stimuli. The remaining 50% were recognition stimuli not used in the dichotic presentation.

Design

A preliminary 3x2 between-subject, analysis of variance design was utilized to study the relation of age (A) and sex (S) to speech-sound discrimination performance. An increase in speech-sound

discrimination with age was expected to be revealed in a significant A effect. An analysis of the linear component of this effect was planned to determine the shape of the function. More accurate speech-sound discrimination on the part of females as compared to that of males was expected to be revealed in a significant S effect.

At each age level, 120 Ss, 60 of each sex, were divided into three groups on the basis of their performance on the speech-sound discrimination task. The result was nine groups of 40 Ss each. For analysis of the dichotic recognition scores, a 3x3x2x2 between-within-subjects analysis of variance design was utilized, the between factors being age (A), level of discrimination ability (D), and the within factors being type of stimulus material (M), and ear of presentation (E).

An increase in dichotic listening performance with age was expected to be revealed in a significant A effect. An analysis of the linear component of this effect was planned to determine the shape of the function. A significant MxE interaction was expected, representing a right-ear advantage for consonant-varied stimuli and a left-ear advantage for vowel-varied stimuli.

The predicted increase of ear-asymmetry with age would be evidenced by a significant AxMxE interaction. An increase in the magnitude of ear asymmetry with levels of discrimination was expected to be revealed in the DxMxE interaction. Analysis of the simple effects

involved in this interaction was planned in order to assess the relationship between level of discrimination ability and dichotic recognition performance at <u>each combination</u> of levels of M and E. This analysis was designed to test the following specific predictions: (1) an increase in right-ear recognition of consonant-varied material with increasing levels of discrimination performance; (2) a decrease in right-ear recognition of vowel-varied material with increasing levels of discrimination performance; (3) a decrease in left-ear recognition of consonant-varied material with increasing levels of discrimination performance; and (4) no change in left-ear recognition of vowel-varied material with different levels of discrimination performance.

CHAPTER V

RESULTS

A summary of the preliminary analysis of variance of speech-sound discrimination scores for the two factors of age (A) and sex (S) is presented in Table 1. The main effect for A was highly significant ($F = 38.24$, $df = 2,354$; $p < .001$). The variance attributable to A was due almost entirely to the linear component ($F_{linear} = 76.27$, $df = 1,354$; $p < .001$) of the effect, reflecting increased discrimination performance with increases in age. The mean discrimination score was 19.97 for ages 7-8, 21.55 for ages 9-10, and 22.85 for ages 11-12. The maximum discrimination score possible was 30.

The significant S main effect ($F = 16.15$, $df = 1,354$; $p < .001$) reflects the fact that in general, females discriminated speech-sounds more accurately than did males. The mean discrimination score for females was 21.99, and for males, 20.91. The differences due to sex within each age level are illustrated in Figure 1.

The division of each age group into three discrimination levels produced nine groups with mean discrimination scores ranging from 16.93 to 25.40. The mean discrimination scores associated with the discrimination levels within each age group are illustrated in Figure 2. The mean differences among discrimination levels within each age ranged from a minimum of 2.58 to a maximum of 4.27.

Table I

Summary of Analysis of Variance of Discrimination Scores

Source	SS	df	MS	F	p
A(Age)	500.24	2	250.12	38.24	$<.001$
S(Sex)	105.62	1	105.62	16.15	$<.001$
AxS	8.52	2	4.26	0.65	
Error	2314.82	354	6.54		
Total	2929.20	359			

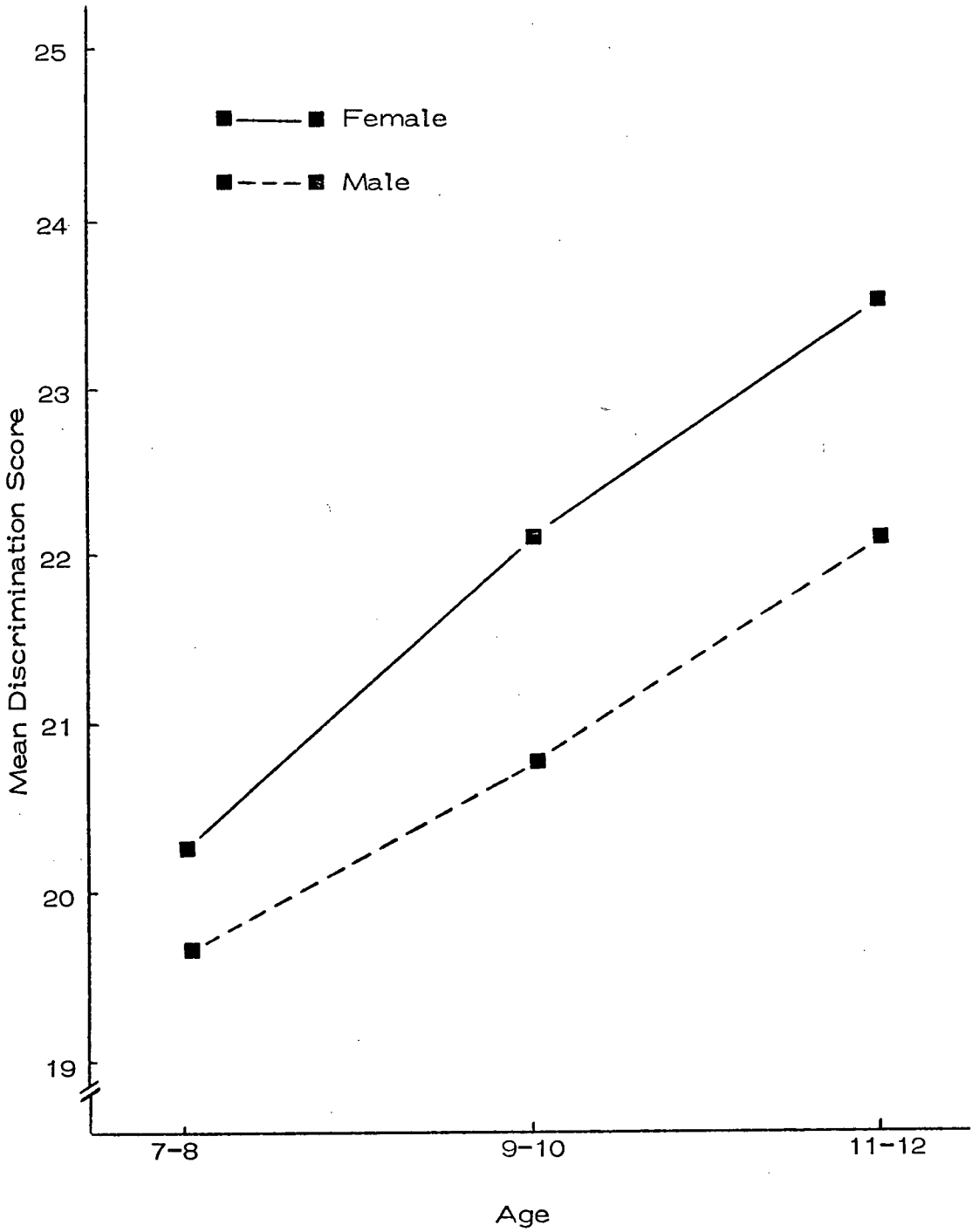

Fig. 1. Relationship of speech-sound discrimination performance to age and sex.

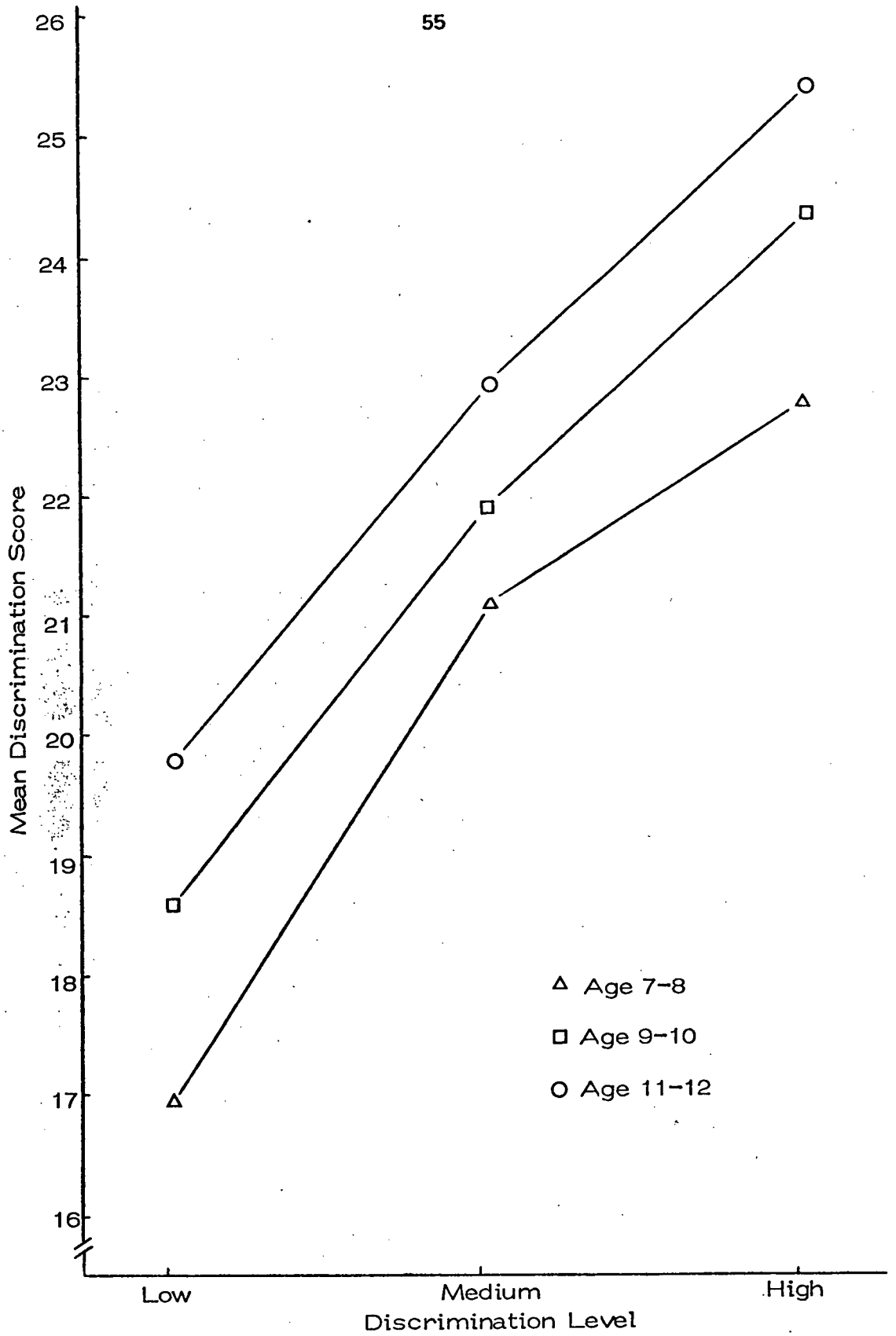

Fig. 2. Speech-sound discrimination performance at each of the discrimination levels within each age level.

When the sex differences were redefined in terms of percentage composition at each discrimination level, females were found to make up only 39.17% of the low discrimination groups, 49.17% of the middle discrimination groups,and 61.67% of the high discrimination groups. This composition difference is illustrated in Figure 3.

A summary of the analysis of variance of dichotic stimulation recognition scores for the four factors of age (A), speech-sound discrimination level (D), stimulus material (M), and ear of presentation (E) is presented in Table II.

The main effect for A was significant ($F = 13.94$, $df = 2,351$, $p < .001$). A highly significant proportion of the variance attributable to A was due to the linear component ($F_{linear} = 26.50$, $df = 1,354$; $p < .001$) of the effect, reflecting increased performance with increase in age. The mean recognition score was 7.44 for ages 7-8, 7.92 for ages 9-10, and 8.13 for ages 11-12.

In contrast with the main effect for A, the main effect for D was not significant, showing only a negligible change in recognition performance across discrimination levels, and that in a negative direction. The mean recognition score was 7.91 for the low discrimination group, 7.81 for the middle discrimination group, and 7.77 for the high discrimination group.

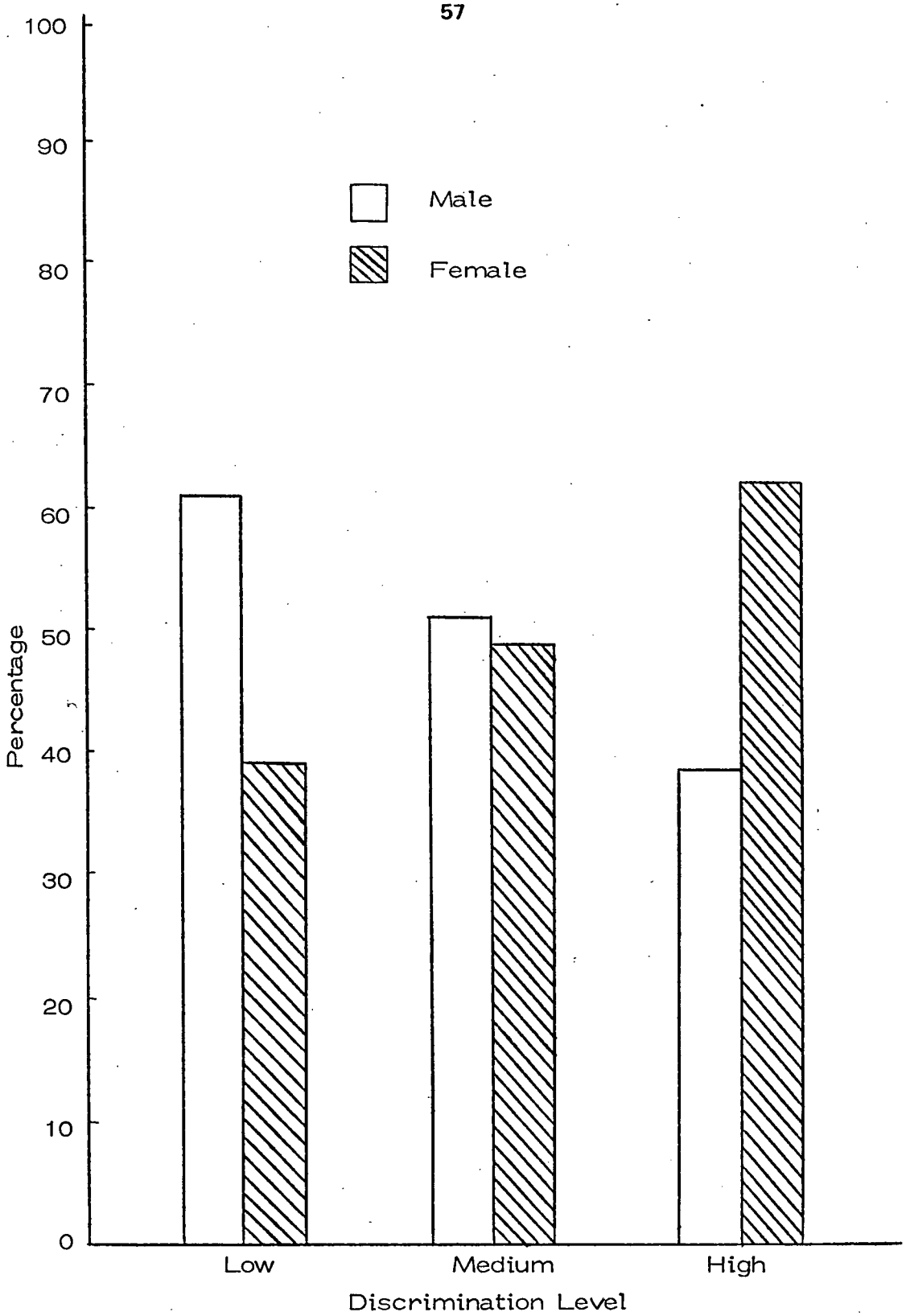

Fig. 3. Sex composition of the groups corresponding to the three discrimination levels.

Table II

Summary of Analysis of Variance of Recognition Scores

Source	SS	df	MS	F	p
A (Age)	119.30	2	59.65	13.94	$<.001$
D(Discrimination)	5.54	2	2.77	0.65	
AxD	2.77	4	0.69	0.16	
Error (b)	1503.04	351	4.28		
M (Material)	45.51	1	45.51	21.17	$<.001$
MxA	1.27	2	0.64	0.30	
MxD	13.05	2	6.53	3.03	$<.05$
MxAxD	0.11	4	0.03	0.01	
Error (w_1)	753.06	351	2.15		
E (Ear)	4.01	1	4.01	2.17	
ExA	4.37	2	2.19	1.18	
ExD	5.73	2	2.87	1.55	
ExAxD	7.81	4	1.95	1.06	
Error (w_2)	648.54	351	1.85		
MxE	98.17	1	98.17	71.14	$<.001$
MxExA	19.85	2	9.93	7.19	$<.001$
MxExD	42.93	2	21.47	15.55	$<.001$
MxExAxD	13.38	4	3.35	2.43	$<.05$
Error (w_3)	486.21	351	1.38		
Total	3774.65	1439			

The main effect for M was significant ($F = 21.17$, $df = 1,351$; $p < .001$), reflecting the difference in difficulty in identifying consonant-varied nonsense syllables versus vowel-varied nonsense syllables. Consonant identification proved to be the more difficult task, yielding a mean recognition score of 7.65. The mean recognition score for vowel-varied nonsense syllables was 8.01.

Two of the double interactions were found to be significant. A significant MxD interaction ($F = 6.53$, $df = 2,351$; $p < .05$) reflects the fact that differences in recognition performance across discrimination level vary with the stimulus material presented. These interactive effects are illustrated in Figure 4. With consonant-varied material, virtually no difference in recognition performance is evident across discrimination levels, the mean difference between the low and high discrimination groups being only 0.09. With vowel-varied material, however, a substantial decrease in recognition performance is associated with increasing discrimination levels. The mean recognition score for the low discrimination group was 8.22, the middle discrimination group, 7.97, and the high discrimination group, 7.83.

The MxE interaction was highly significant ($F = 71.14$, $df = 1,351$; $p < .001$). This effect is illustrated in Figure 5. Consonant-varied stimuli were more frequently identified correctly when they were

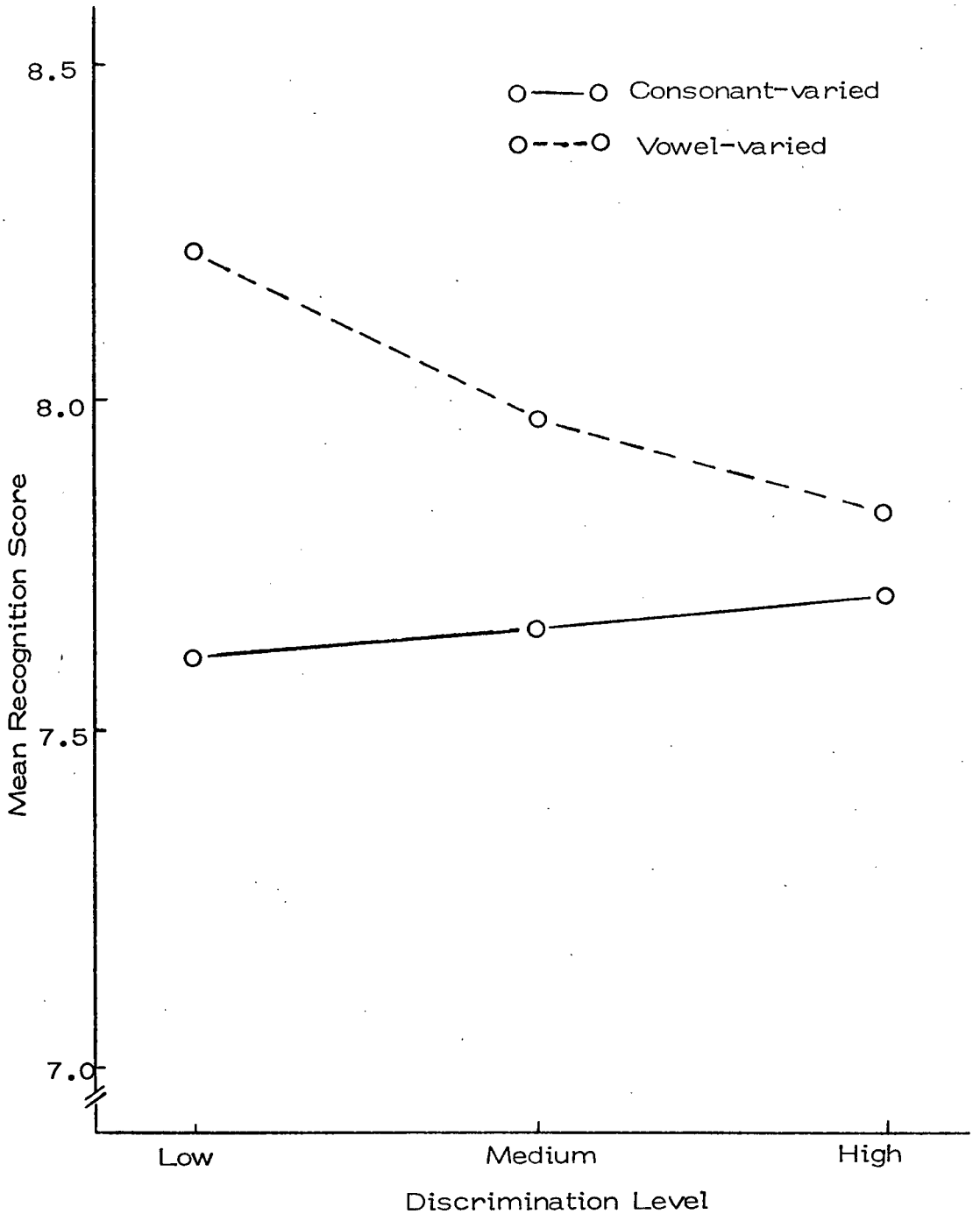

Fig. 4. Recognition performance at each discrimination level as a function of stimulus material.

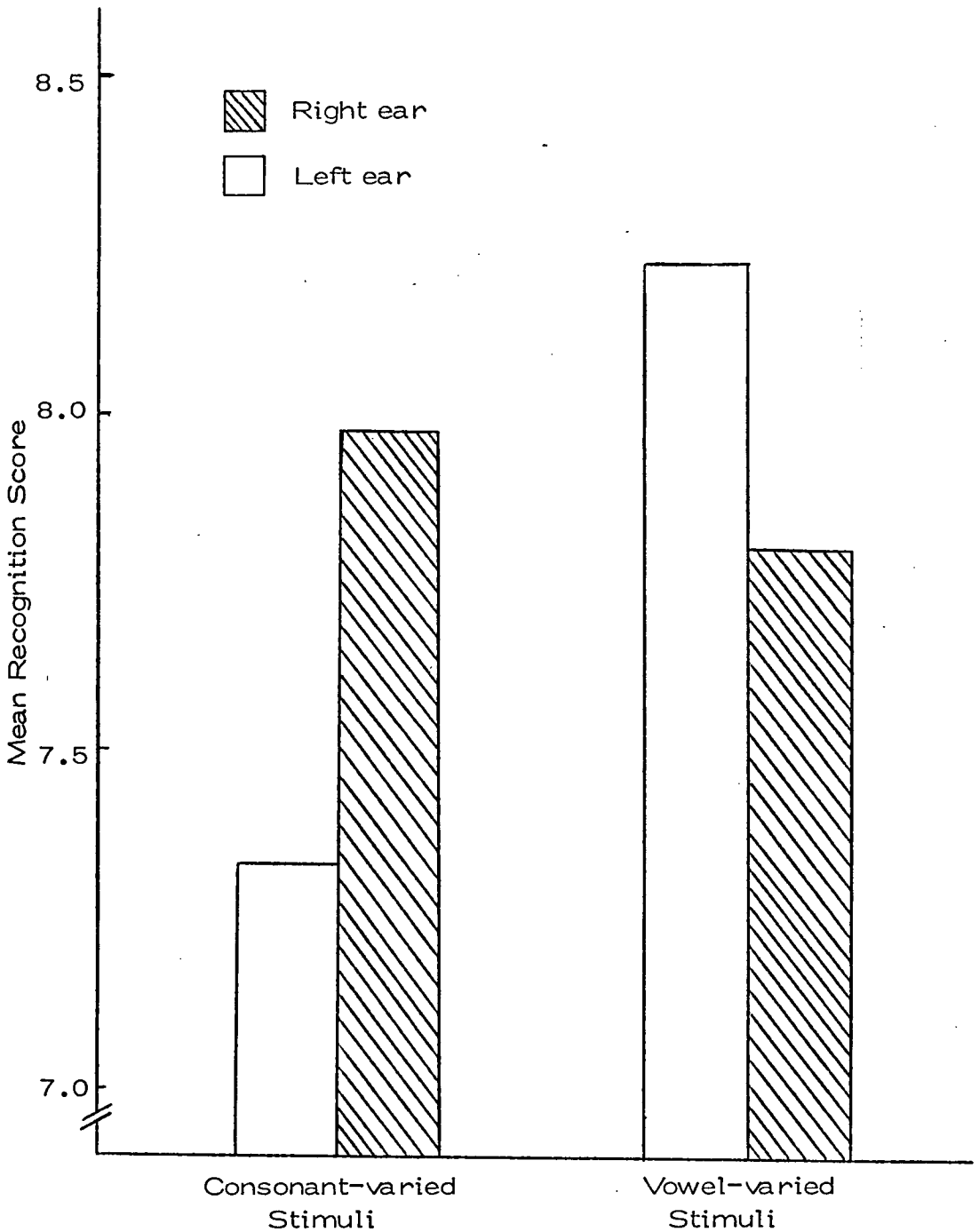

Fig. 5. Recognition performance as a function of stimulus material and ear of presentation.

presented to the right ear, and vowel-varied stimuli were more frequently identified correctly when they were presented to the left ear. The percentage right-ear preference for consonants was 4.10 and the percentage left-ear preference for vowels was 2.61. This was calculated by dividing the difference between mean recognition scores for right and left ears by the sum of the mean recognition scores for both ears, and multiplying by one hundred.

Two of the triple interactions were significant, MxExA ($F = 7.19$, $df = 2,351$; $p < .001$) and MxExD ($F = 15.55$, $df = 2,351$; $p < .001$). Since the magnitude of ear asymmetries is reflected in the MxE effect, the significance of the (MxE)xA interaction can be interpreted as an indication that the degree of ear asymmetry differs with levels of A. The data that are shown in Figure 6 illustrate, in terms of percentage ear preference, an increasing magnitude of ear asymmetries with increases in levels of age for both stimulus materials. No ear preference is present for vowel-varied material in the lower age group, while a moderate ear preference is already present for consonant-varied material. The largest increase in ear preference takes place between ages 7-8 and 9-10 for the consonant-varied material and ages 9-10 and 11-12 for the vowel-varied material. The average degree of ear preference across material is 1.57% for ages 7-8, 3.31% for ages 9-10, and 4.97% for ages 11-12.

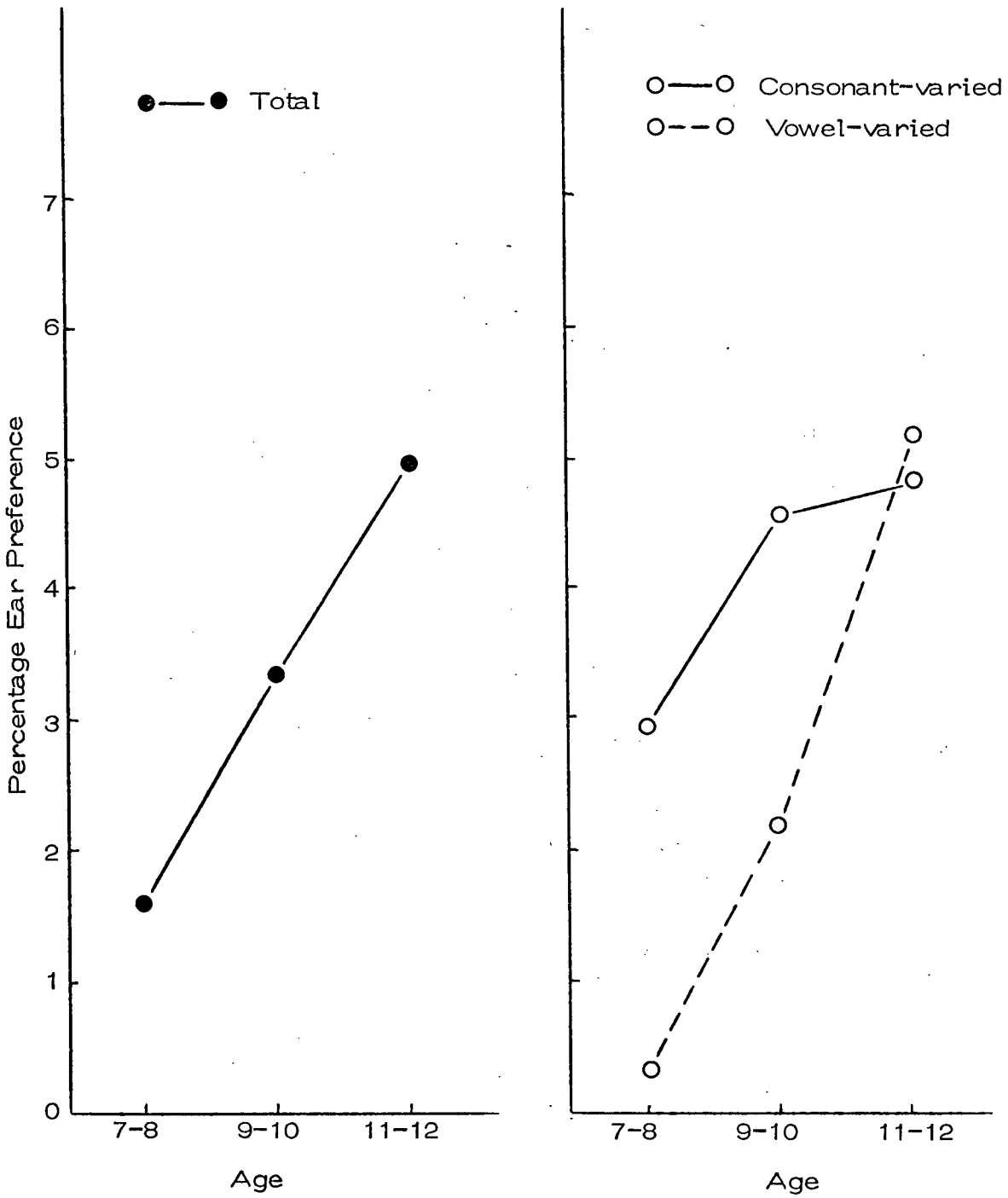

Fig. 6. Magnitude of ear asymmetry at each age level for stimulus materials combined and for each material separately.

In following a similar approach as described above for the (MxE)xA interaction, the significance of the (MxE)xD interaction can be interpreted as an indication that the magnitude of ear asymmetry differs with levels of D. The data that are shown in Figure 7 illustrate, in terms of percentage ear preference, an increasing degree of ear asymmetry with increasing levels of discrimination performance for both stimulus materials. The left-ear preference for vowel-varied material increased from 0.71% in the low discrimination group to 5.48% in the high discrimination group. The right-ear preference for consonant-varied material increased from 2.57% in the low discrimination group to 7.09% in the high discrimination group.

The MxExD interaction is illustrated in terms of mean recognition scores in Figure 8. The data represent a comparison of left- versus right-ear recognition performance across discrimination levels for each stimulus material. For consonant-varied material, right-ear recognition <u>increased</u> with increases in level of speech-sound discrimination performance. Left-ear recognition however, <u>decreased</u> with increasing levels of discrimination performance. The difference in the direction of the relationship between discrimination level and recognition performance was reflected in the significant

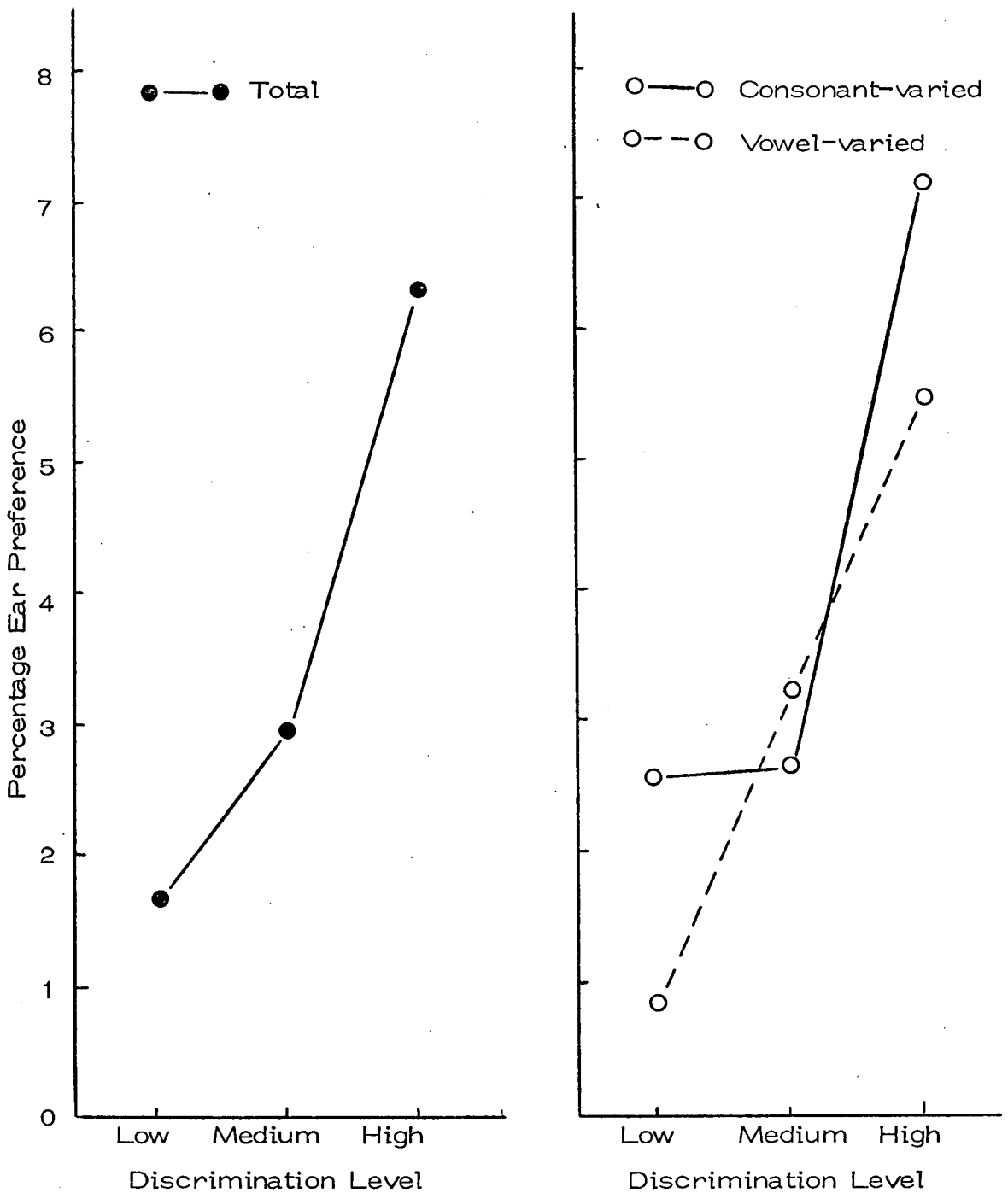

Fig. 7. Magnitude of ear asymmetry at each discrimination level for stimulus materials combined and for each material separately.

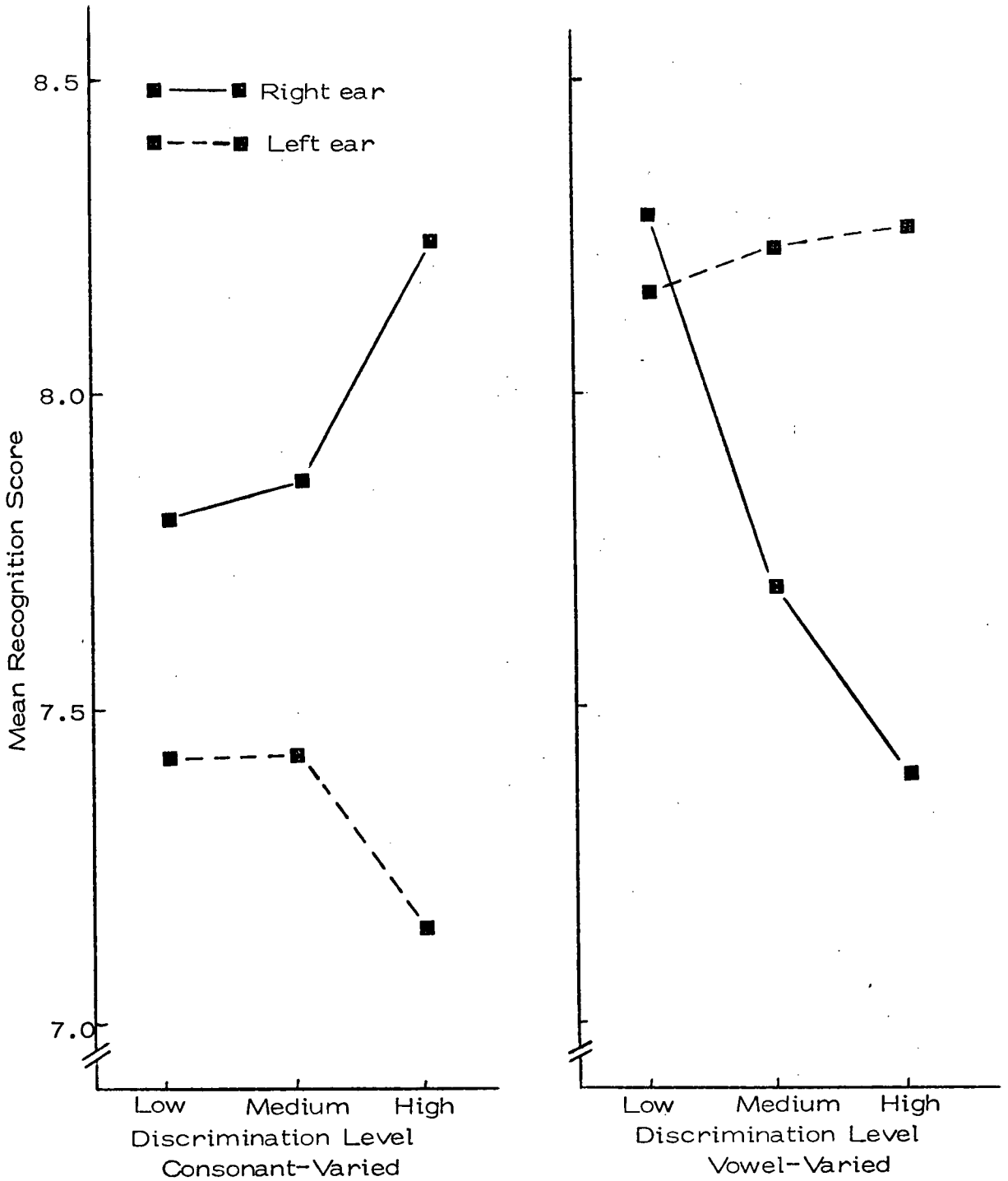

Fig. 8. Recognition performance at each discrimination level as a function of ear of presentation and stimulus material.

ExD_{linear} effect for the consonant-varied material (F = 10.65, df = 1,351; $p < .001$). A similar analysis was carried out for the vowel-varied stimuli. The ExD_{linear} effect in this case yielded an F of 20.66 (df = 1,351, $p < .001$). Although these effects are significant in both cases, the nature of the interactive effects of ExD_{linear} is different for vowel-varied stimuli than it is for consonant-varied stimuli. The interactive effects of ExD_{linear} for vowel-varied material are almost entirely due to the decrease in right-ear recognition with increasing levels of discrimination. While the mean decrease for right-ear recognition performance across discrimination levels is 0.88, the mean increase for left-ear recognition performance is only a negligible 0.09. Analysis of the simple main effects involved in this interaction showed that the decrease in right-ear performance was highly significant (F = 32.66, df = 1,351; $p < .001$), while the slight increase in left-ear performance was not significant (F = 0.51, df = 1,351).

This pattern of results is illustrated in an alternative manner in Figure 9. Right-ear performance increased with consonant-varied material and decreased with vowel-varied material with increasing levels of speech-sound discrimination. Left-ear performance decreased with consonant-varied material but showed negligible change with vowel-varied material with increasing levels of speech-

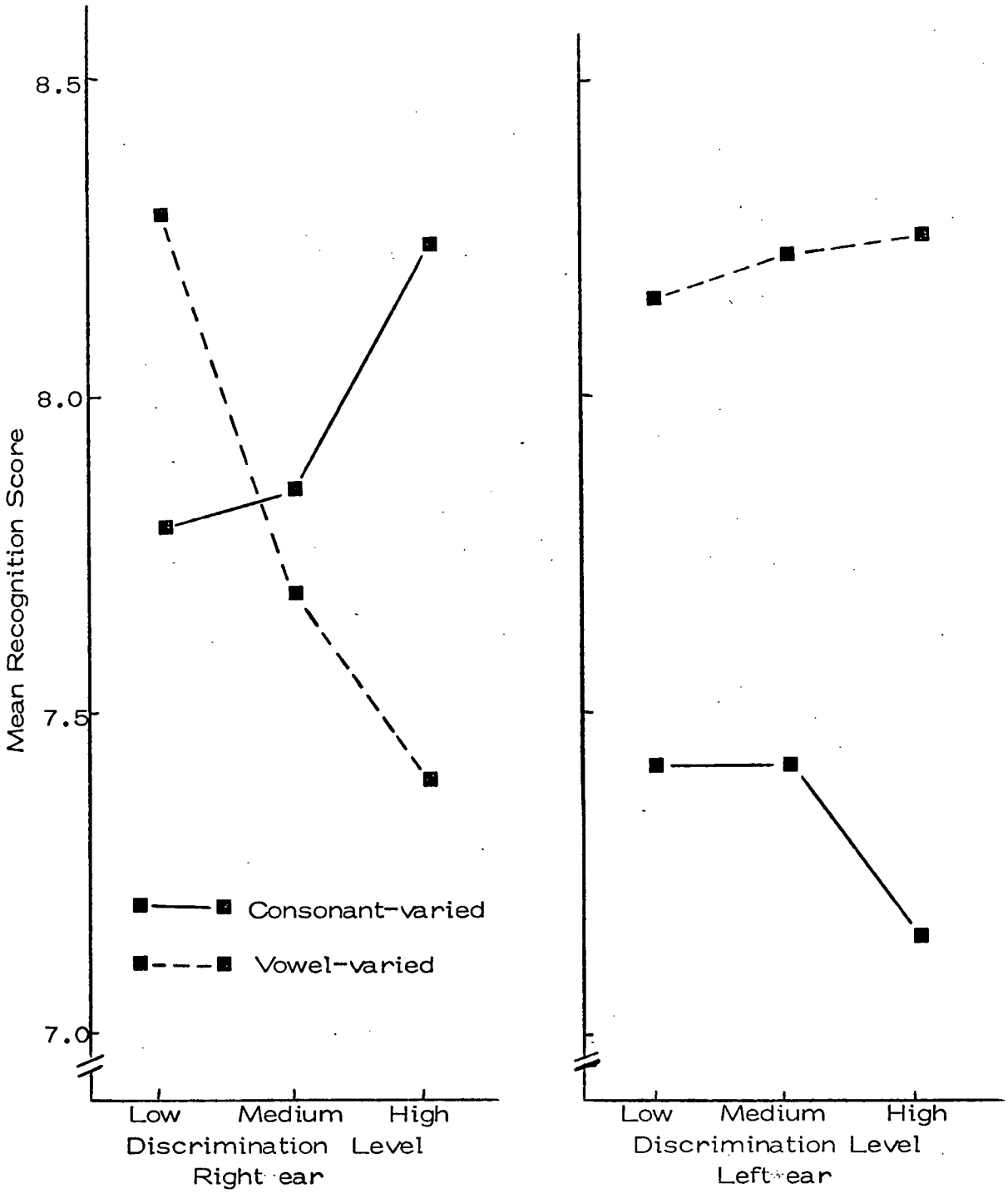

Fig. 9. Recognition performance at each discrimination level as a function of stimulus material and ear of presentation.

sound discrimination.

The significant quadruple MxExDxA interaction ($F = 2.43$, $df = 4,351$; $p < .05$) may be approached from two perspectives: changes in the MxExD interaction at differing levels of age, or changes in the MxExA interaction at differing levels of discrimination performance. The (MxExD)xA interaction is illustrated in terms of mean recognition scores in Figures 10 and 11. Although right-ear recognition generally increased with discrimination level for consonant-varied material, there was little change or a decrease in recognition from the low to middle discrimination groups for ages 7-8 and 9-10. And although left-ear recognition generally decreased with discrimination level for consonant-varied material, there was an increase in recognition performance from the low to middle discrimination groups for ages 7-8 and 9-10. Recognition performance for vowel-varied material yielded no differential effects on the shape of the DxE functions. That is, regardless of age, left-ear recognition of vowel-varied material showed a consistent decrement with increasing levels of discrimination. And, regardless of age, right-ear recognition of vowel-varied material did not vary with discrimination level. However, a reversal in the direction of ear asymmetry was observed for subjects at the low discrimination levels in the 7-8 and 9-10 age groups. The right versus the left ear for these

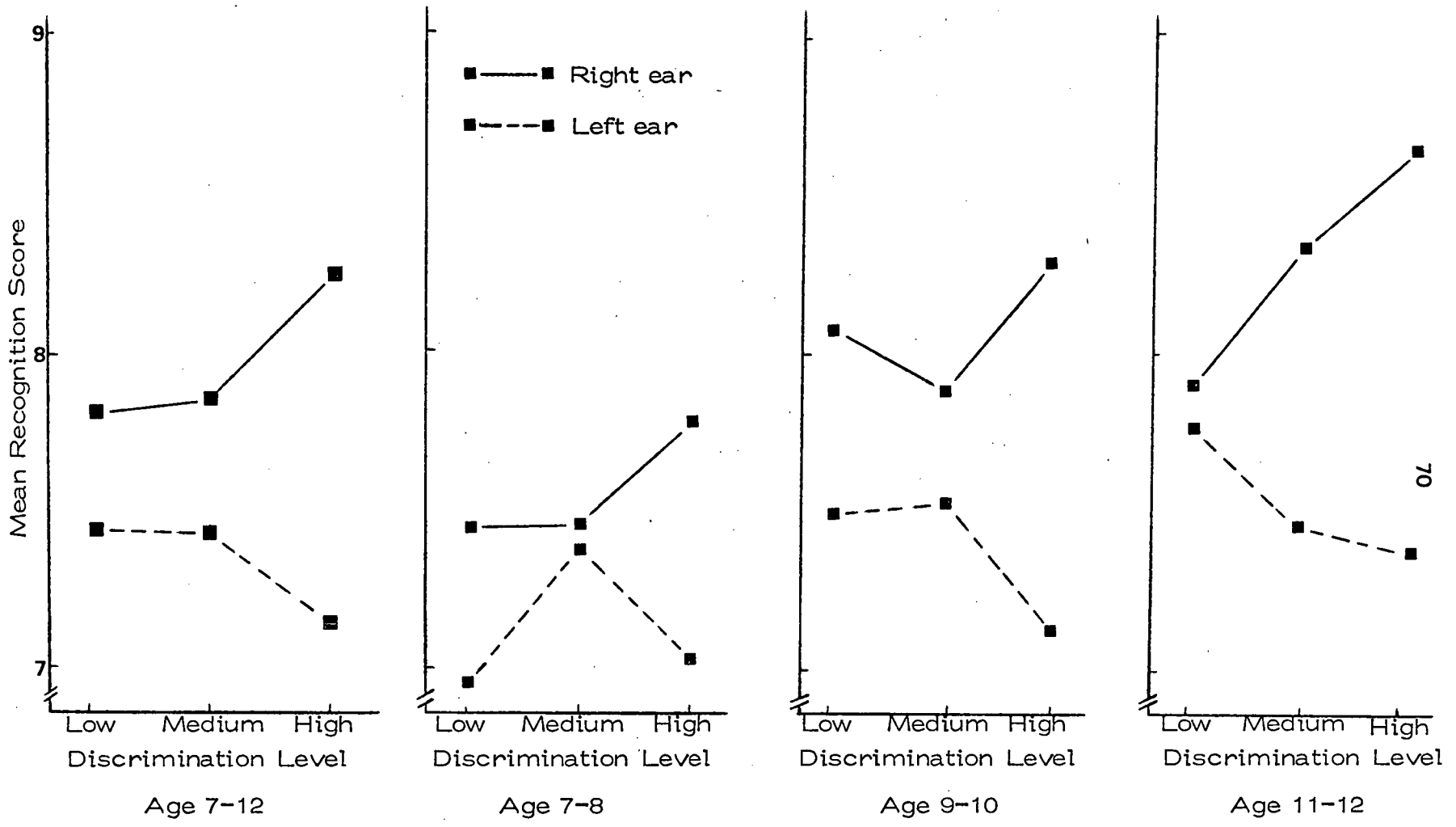

Fig. 10. Recognition scores for consonant-varied material at each combination of levels of discrimination ability and age as a function of ear of presentation.

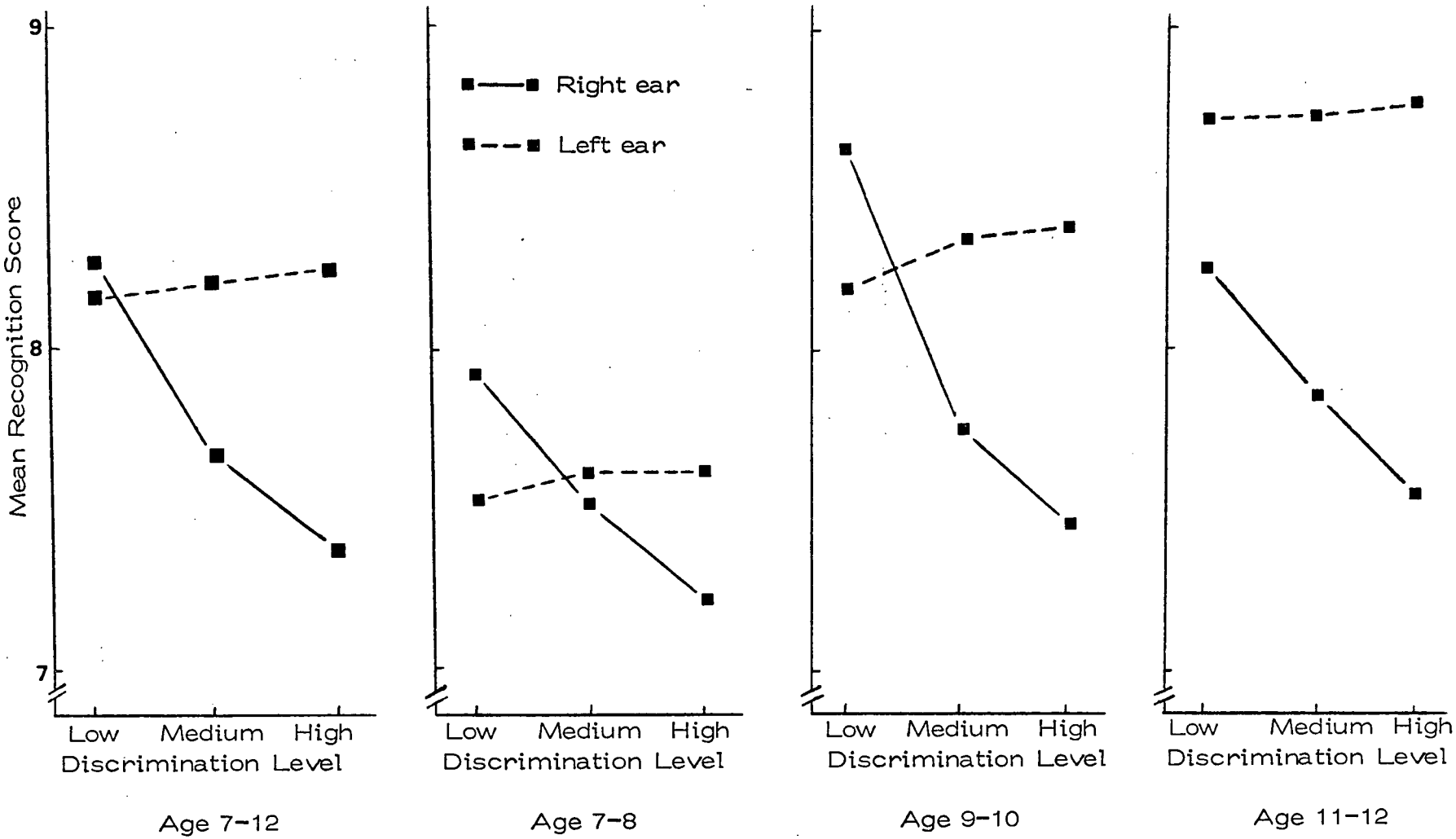

Fig. 11. Recognition scores for vowel-varied material at each combination of levels of discrimination ability and age as a function of ear of presentation.

two groups combined yielded an F of 4.93 (df = 1,351; $p < .05$).

This same (MxExD)xA interaction is illustrated in terms of percentage ear preference in Figure 12. The magnitude of ear preference increased with discrimination level in every instance except for the low to middle discrimination groups for ages 7-8 and 9-10. In these cases there was a decrease in magnitude of ear asymmetry for both vowel-varied material and consonant-varied material. Also the low discrimination groups for these two ages showed right-ear preferences for both vowel-varied and consonant-varied material.

The (MxExA)xD interaction is illustrated in terms of percentage ear preference in Figure 13. While the middle and high discrimination groups showed an increase of ear asymmetry with age, the low discrimination group showed a decrease in ear asymmetry with age — from a right-ear preference for both materials to relatively no ear asymmetry for either material.

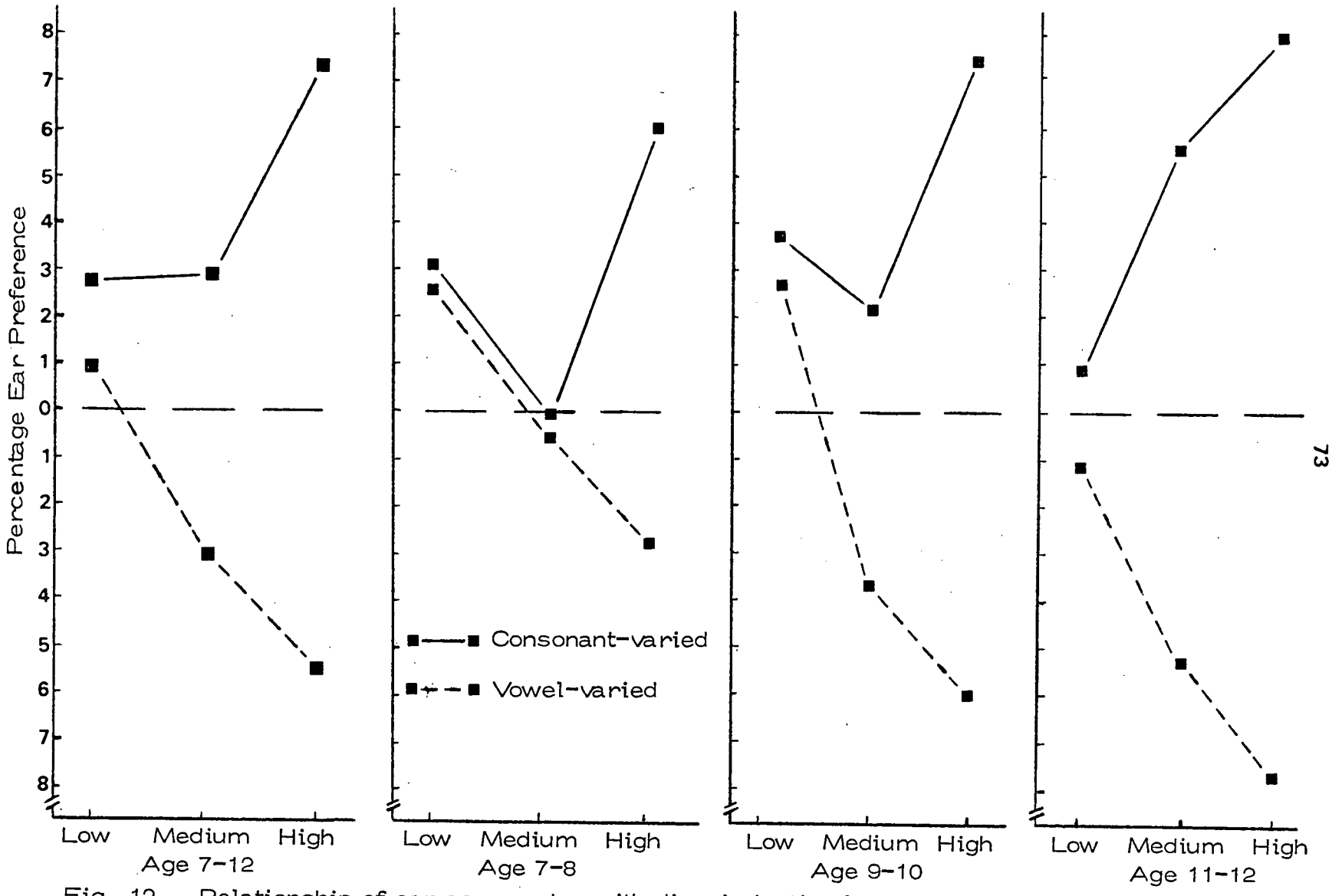

Fig. 12. Relationship of ear asymmetry with discrimination level and stimulus material across ages and within each age group.

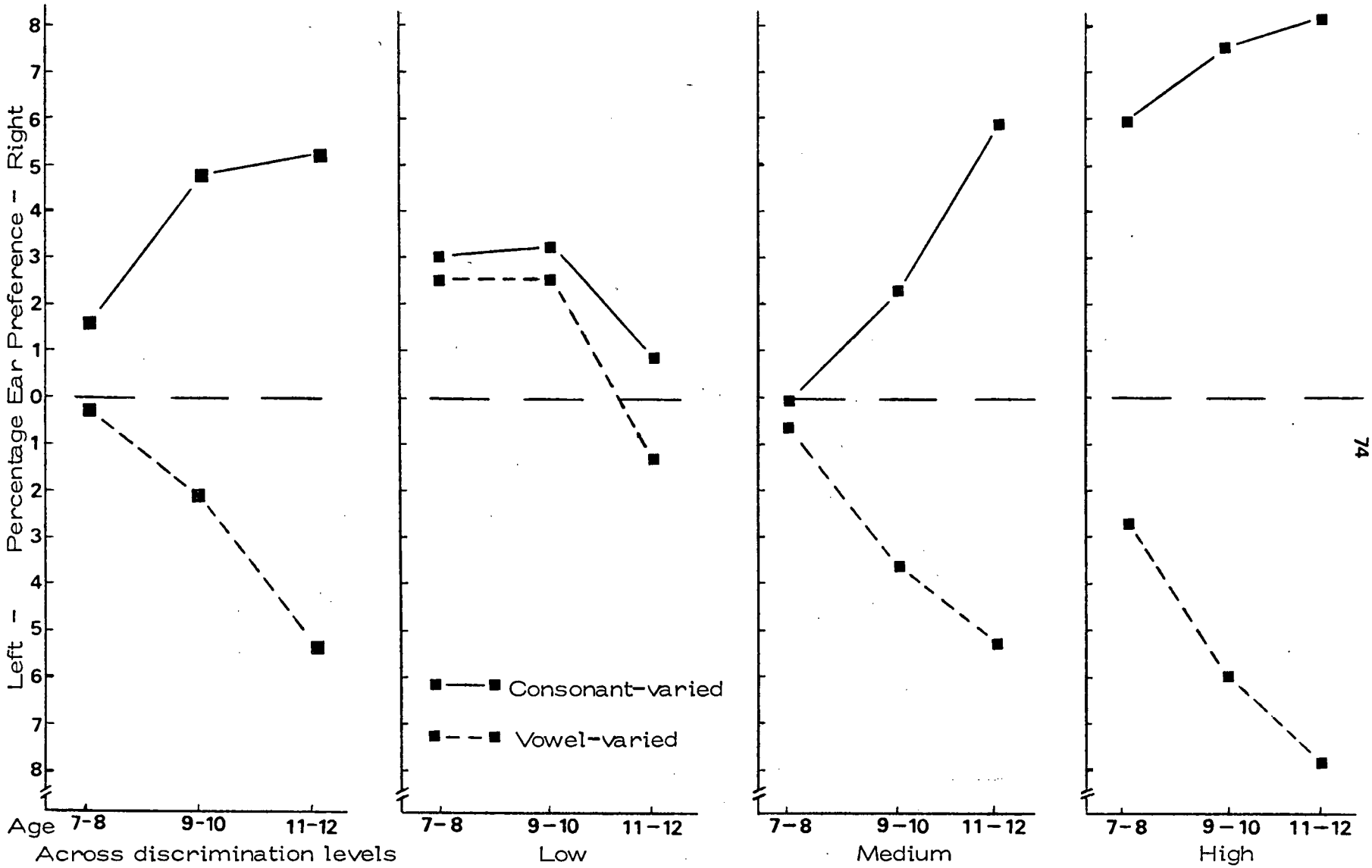

Fig. 13. Relationship of ear asymmetry with age and stimulus material across discrimination levels and within each discrimination level.

CHAPTER VI

DISCUSSION

Of essential importance to the present experiment are the results concerning the relationship between ear asymmetry and speech-sound discrimination. In order to facilitate discussion of this relationship, however, the findings regarding the direction of ear asymmetries will be commented upon first.

Direction of Ear Asymmetries

The finding that nonsense syllables differing in initial consonant are more frequently identified when they are presented to the right ear than when they are presented to the left ear is consistent with previous dichotic listening experiments in which speech stimuli were used. The explanation most compatible with this finding, as well as with previous findings, is that there is present in the left-hemisphere a speech processor or linguistic mechanism for processing encoded acoustical cues such as those integral to the identification and recognition of stop consonants. A right-ear, rather than a left-ear, advantage is presumably obtained because of the greater efficiency of the contralateral auditory pathway relative to that of the ipsilateral pathway.

As for recognition of nonsense syllables differing in the medial vowel, the general finding was that significantly more stimuli were

recognized when they were presented to the left ear than when they were presented to the right ear. Although this result was expected, it is not a typical finding in the dichotic stimulation research. Usually, vowel-identification yields varying results, depending on both the nature of the task and the stimuli used. Even though the vowel stimuli in the present experiment contained encoded acoustical cues, a right-ear advantage was not anticipated, as the non-language set given the Ss was expected to result in these cues being made irrelevant to the identification of the stimuli. The lack of a right-ear preference with the vowel-varied nonsense syllables supports the previous findings that the mere presence of encoded acoustical cues is not a sufficient condition for the production of a right-ear advantage. These results also emphasize the importance of task variables in influencing the direction of ear differences, especially when a variety of cues are available to serve as a basis for the identification of the dichotic stimuli.

The usual explanation offered for ear preferences in dichotic listening tasks is that the superior performance is a reflection of a specialization or dominance in perceptual processing of the hemisphere contralateral to the preferred ear. Thus in the case of consonant identification, the left hemisphere has been postulated to be specialized for the processing of those encoded attributes necessary

for the identification of consonants. In line with Kimura's bilateral dominance hypothesis, superiority in recognition performance for the left ear has been interpreted as reflecting specialization in right hemisphere function. When the bilateral dominance hypothesis is applied to these data, the right-ear preference would presumably be interpreted as being due to the processing of the cues for which the right hemisphere was specialized.

The alternative interpretation put forward by Spellacy and Blumstein (1970), and emphasized in the present experiment, is that only the specialization of the left hemisphere for the processing of encoded acoustical cues need be postulated to account for both right- and left-ear advantages. As information relevant to these alternative hypotheses is contained in the results describing the nature of the relationship between ear asymmetry and speech-sound discrimination, further assessment of these interpretations will be deferred until that relationship has been discussed.

Although the general finding was that an apparent left-ear preference occurred in the recognition of vowel-varied nonsense syllables, two of the nine groups showed a significant reversal of this trend. A right-ear preference for vowel-varied stimuli is fairly commonplace in the literature (Goodglass, 1973; Haggard, 1971; Spellacy & Blumstein, 1970; Studdert-Kennedy & Shankweiler, 1970;

Weiss & House, 1971), and in itself is not cause for surprise. The right-ear advantage in these studies was presumably a result of a task which resulted in the encoded cues being the more salient attributes for identification. In this particular experiment, however, the experimental stimuli were presented in series with melodies and sound effects, presumably creating a nonlanguage set. That is, the encoded cues would not be expected to be the more relevant attributes for recognition. Thus, a right-ear advantage with vowel-varied material was unexpected. This finding is also somewhat resistent to immediate explanation. That the phenomenon may be associated with the relationship between ear asymmetry and speech-sound discrimination is suggested by the fact that the two groups showing the right-ear preference for the recognition of vowel-varied nonsense syllables are also the two groups with the greatest number of errors in the speech-sound discrimination task. Thus further attempts to explain this phenomenon will be deferred to the discussion of the relationship of ear asymmetry to speech-sound discrimination below.

In addition to differing in the direction of ear asymmetries, recognition of vowel-varied stimuli also differed from recognition of consonant-varied stimuli in the level of difficulty of the task. The finding that vowel-varied stimuli are recognized or identified more often than are consonant-varied stimuli has been a fairly reliable one in dichotic stimulation studies (Goodglass, 1973;

Kirstein & Shankweiler, 1969; Shankweiler & Studdert-Kennedy, 1967, 1970; Spellacy & Blumstein, 1970). Although no explanation has been offered in the literature, one possible reason for this may be that there are more cues relevant to the identification of vowels than there are to the identification of consonants. In addition to the encoded acoustical cues on which consonant-identification depends, vowels also possess steady-state frequency properties and greater variation in duration.

Sex Differences

Also of interest in the present experiment were sex differences in speech-sound discrimination. The analysis of variance of the speech-sound discrimination scores yielded a highly significant main effect for Sex, with females performing significantly better than males in all three age groups. This finding is in agreement with previous research on speech-sound discrimination (Goldman et al., 1970). The results are also consistent with developmental and neurological evidence indicating the maturational advantage females show in language and perceptual development (Sabir, 1966; Terman & Tyler, 1954). Given a close positive relationship between speech-sound discrimination and ear asymmetry, one would expect females to show greater ear asymmetry than do males. Evidence to this effect comes from the developmental dichotic listening study by

Neufeld (1971) in which females showed significant ear asymmetry at an earlier age than did males in the case of both consonant- and vowel-varied material.

Ear Asymmetry and Speech-Sound Discrimination

It would appear from the results of the present experiment that the phenomena of ear asymmetry and speech-sound discrimination are intimately related, although the relationship is not as straightforward as was anticipated. For an examination of the relationship between the two phenomena, it was necessary to have a speech-sound discrimination task sensitive enough to define statistically separate groups within the normal population. As most speech discrimination instruments are constructed for the purpose of differentiating between the normal and the clinical population, this requirement was a fairly stringent one. The positive results of the preliminary analysis of variance with the speech-sound discrimination data confirmed that the present task possesses this essential requirement.

Although no standardization data are available for direct comparison because of the different age groupings used in the experiment, when the averages for the ages involved in the experimental age groupings are computed, there is fairly close agreement between the standardization data and the experimental data. This comparison

is illustrated in Figure 14. It would appear from this comparison that the modification in the administration of the task had relatively little effect, if any, on the discrimination performance of the subjects.

The present data indicate quite clearly that both speech-sound discrimination and ear asymmetry are developmental phenomena. If both ear asymmetry and speech-sound discrimination are related to the specialization of the left hemisphere for speech processing as was hypothesized, one would expect some degree of correspondence in their development. Also, consistency with other supposed manifestations of this developing lateralization for the perceptual processing of speech stimuli would be expected. A comparison of the developmental trends for degree of ear asymmetry and speech-sound discrimination between the ages of 7-8 and 11-12 is illustrated in Figure 15. A fairly strong positive linear relationship with age is demonstrated for both variables.

Although the finding of increased asymmetry with age is somewhat inconsistent with most other developmental dichotic stimulation studies, it would appear that the discrepancies can be explained as a by-product of the methodological inadequacies inherent in the multiple-pair-per-trial recall paradigms used in these studies. As was noted earlier, it seems likely that the results of these studies

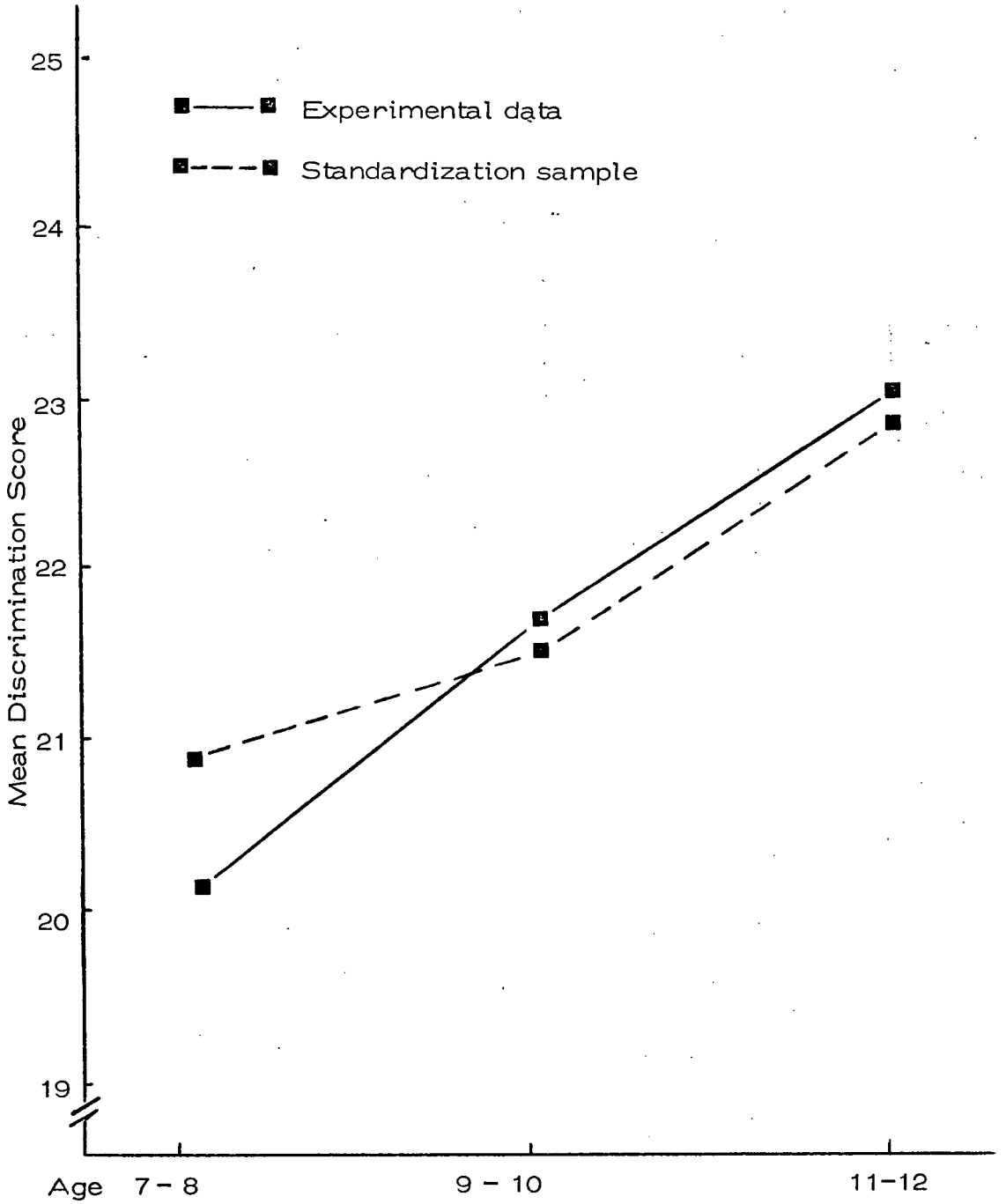

Fig. 14. Comparison of standardization data and experimental data in terms of mean discrimination scores for various age levels.

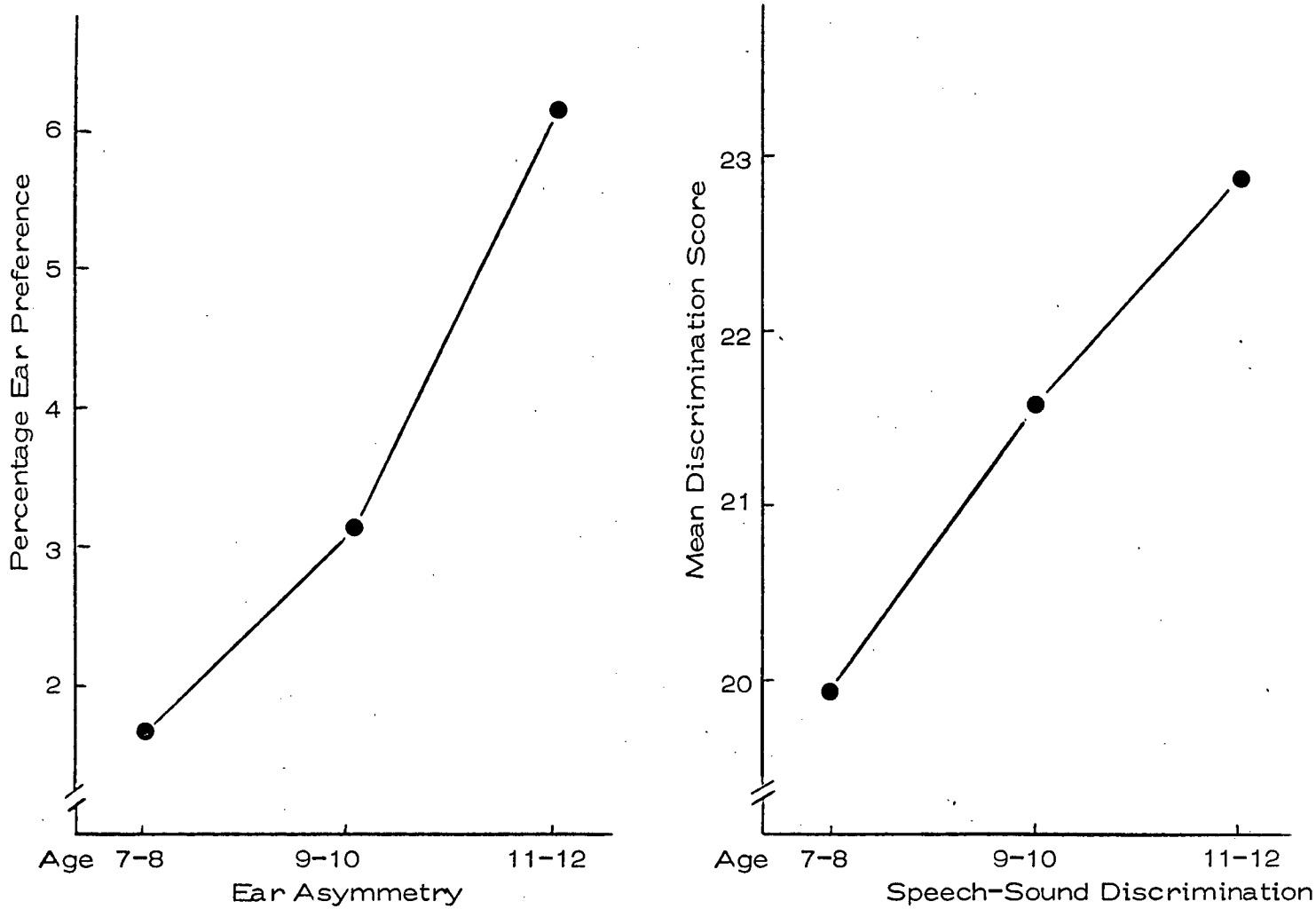

Fig. 15. Comparison of developmental trends for ear asymmetry and speech-sound discrimination.

have been contaminated by the influence of order of report factors and short-term memory capacity on dichotic stimulus identification. Thus, they may not have been sensitive to changes in the hemispheric asymmetry associated with speech processing. When data from these studies are re-evaluated in terms of the relative incidence rather than the magnitude of ear preference of different age levels (Bryden, 1970; Geffner & Hochberg, 1971; Knox & Kimura, 1970), or when a one-pair-per-trial rather than a multiple-pair-per-trial paradigm is used (Berlin et al., 1974), the results are more in accord with the present findings.

The developmental results of the present study are also consistent with the clinical literature which indicates, as was noted above, a gradual increase in left-hemisphere involvement in language function during the elementary school years. Thus the similarity in developmental trends of both ear asymmetry and speech-sound discrimination, as well as the consistency with other assumed measures of left-hemisphere specialization in speech processing, lend indirect support to the existence of a relationship between ear asymmetry and speech-sound discrimination. These findings also support the association of both phenomena with left-hemisphere specialization in language functions.

The most compelling support for a relationship between ear

asymmetry and speech-sound discrimination comes from evidence of the changes in both the direction and the degree of ear asymmetry with different levels of speech-sound discrimination. An example of the differentiating effects of discrimination level is given in Figure 16. Although this particular age group as a whole exhibits very little asymmetry in the recognition of vowel-varied nonsense syllables, when the individual Ss are differentiated on the basis of discrimination level, significant ear asymmetry is seen to be present. The degree and direction of ear asymmetry vary with level of speech-sound discrimination performance.

The significant interaction involving discrimination level, stimulus material and ear of presentation reflects a positive linear relationship between the magnitude of ear asymmetry and speech-sound discrimination (see Figure 7). Higher levels of speech-sound discrimination were associated with greater magnitudes of ear asymmetry, while lower levels of speech-sound discrimination were associated with lesser degrees of ear asymmetry. As speech-sound discrimination is a task that involves the sequential analysis and differentiation of encoded acoustical cues, this ability would presumably increase with the developing specialization of the speech processor in the left hemisphere. And, on the basis of evidence concerning the conditions necessary to produce a right-ear preference,

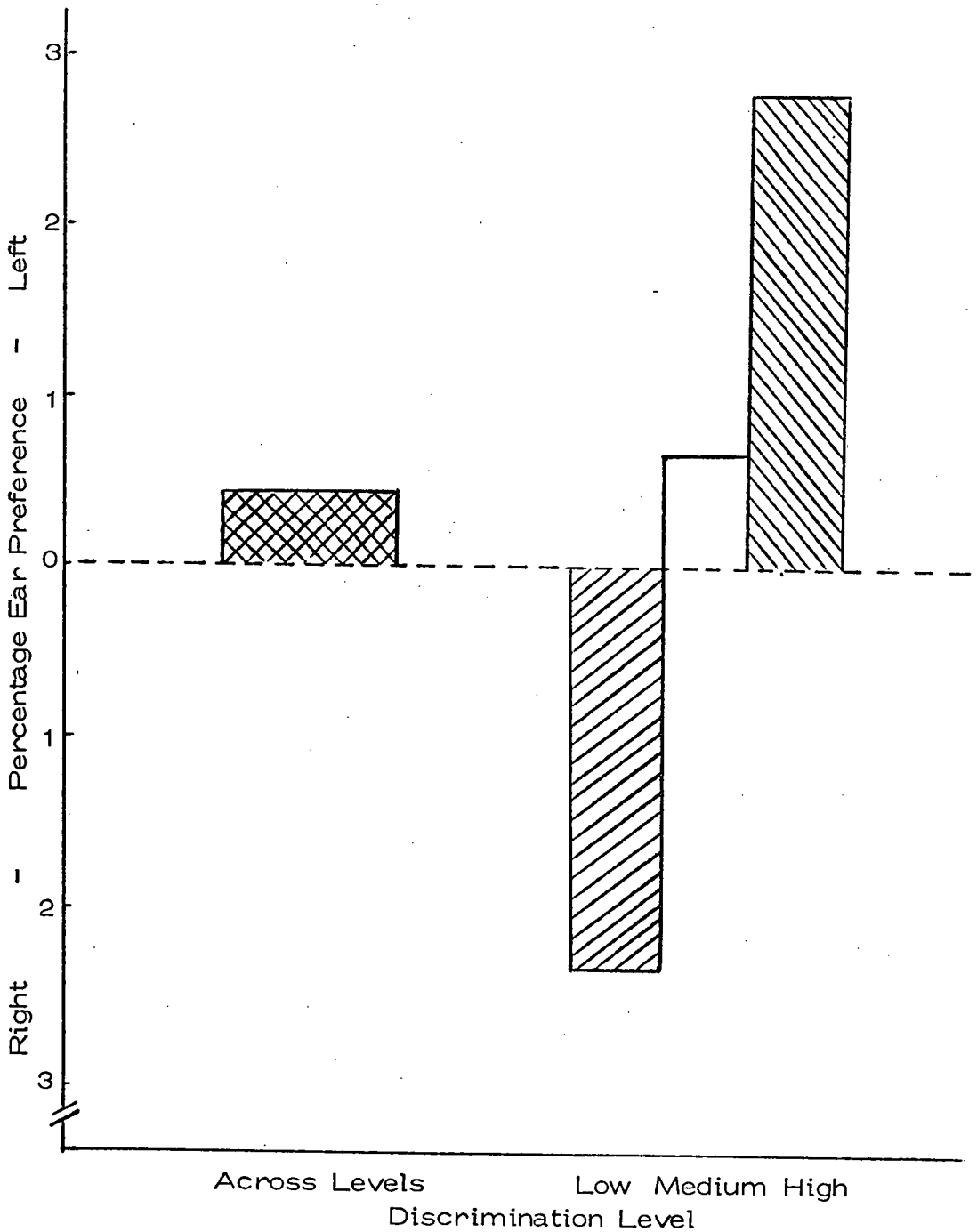

Fig. 16. Ear preference for vowel-varied stimuli in 7-8 year-old subjects across and within speech-sound discrimination levels.

ear asymmetry is also integrally related to the specialization of the speech processor in the left-hemisphere. These considerations suggest that speech-sound discrimination and ear asymmetry are separate and distinct measures of the same phenomenon — the specialization of the left hemisphere for the processing of speech.

The significant positive linear relationship between magnitude of ear asymmetry and speech-sound discrimination may help to shed light on the nature of hemispheric relations, especially with respect to the two alternative interpretations of the left-ear preference, i.e., the unilateral and the bilateral dominance hypotheses. There was negligible change in total recognition performance across speech-sound discrimination levels. Further, there was no significant difference in the strength of the relation between discrimination level and dichotic recognition performance at any of the three age levels (i.e., DxA). Thus the main effect of discrimination level on recognition performance appears to be less important than the way this factor <u>interacts</u> with ear and type of stimulus material.

The significant interaction effects of DxExM are consistent with the unilateral dominance model of hemispheric relations. For the right-ear, an increase in speech-sound discrimination performance was associated with an increase in recognition of consonant-varied stimuli and a decrease in recognition of vowel-varied stimuli.

These results are in line with the assumption that higher levels of speech-sound discrimination reflect a greater degree of left hemispheric specialization for the perception of speech. With increased specialization for the processing of encoded acoustical cues comes enhanced perception of stimuli when these cues are used as a basis for identification. Thus right-ear recognition of consonant-varied stimuli increases with increases in level of speech-sound discrimination. However, with increased specialization for encoded acoustical cues comes a decrement in perception of stimuli when these cues are not present or when they are not used as a basis for identification. Thus right-ear recognition of vowel-varied stimuli progressively decreases with increases in level of speech-sound discrimination.

For the left ear, an increase in speech-sound discrimination performance was associated with a decrease in the recognition of consonant-varied stimuli. However, recognition of vowel-varied stimuli was independent of speech-sound discrimination level (see Figure 9). The rationale for the inferiority in left-ear recognition of consonant-varied material is the progressive lateralization to the left hemisphere of the function involving the perceptual processing of encoded cues. This presumably results in a relative decrement in the perceptual processing of these cues in the right hemisphere. This interpretation is in accord with the present results, and it is

also consistent with the clinical evidence that attests to the decreasing probability with age of disorders in the speech process resulting from damage to the right cerebral hemisphere (Lenneberg, 1967).

The relation between left-ear vowel recognition and speech-sound discrimination is crucial in determining which of the two views — the unilateral or the bilateral dominance hypothesis — provides the more appropriate interpretation. The bilateral dominance hypothesis involves the assumption that there is a right-hemisphere specialization for left-ear advantage stimuli — a specialization that produces a left-ear advantage in the case of vowel-varied stimuli. With increasing specialization would presumably come an increase in left-ear recognition performance for vowel-varied stimuli. The present data are not compatible with this hypothesis in that left-ear recognition of vowel-varied stimuli differed only negligibly at varying levels of discrimination performance.

The unilateral dominance hypothesis involves only the postulation of left-hemisphere specialization for language, and thus leads to the prediction of no significant change in vowel-varied stimulus recognition with increasing levels of discrimination performance. From this view, the left-ear advantage is due to a decrement in right-ear recognition of vowel-varied stimuli rather than to an increment in left-ear recognition of vowel-varied stimuli. This interpretation is in accord with the present results.

Although the nature of the relationship between speech-sound discrimination and ear asymmetry is, in general, a positive one, certain unexpected variations from this trend were observed. The four-way interaction involving ear of presentation, stimulus material, discrimination level and age was significant. This finding may be interpreted to mean that the interactive effects of discrimination level, ear, and type of material are not the same at various levels of the age variable. Or since ExM reflects ear asymmetry, it may be taken to indicate that the relation between discrimination level and the magnitude and/or direction of ear asymmetry differs across age levels. The specific results that contributed to the significance of this effect may be noted by referring to Figure 12. Although the general pattern is an increase in asymmetry with increases in speech-sound discrimination ability, there are evidences of decreases in asymmetry from the low to the middle discrimination levels for both the 7-8 and 9-10 age groups. This is accompanied by a reversal in two cases with respect to the direction of asymmetry for vowel-varied material. The low discrimination groups at both the 7-8 and the 9-10 age levels demonstrated a significant right-ear preference rather than the expected left-ear preference.

This quadruple interaction may also be interpreted to mean that the interactive effects of age, ear, and type of material are not the same at various levels of the discrimination variable. Following the above rationale in which ExM reflects ear asymmetry, this interaction

could be taken to indicate that the relationship between age and magnitude and/or direction of ear asymmetry differs across discrimination levels. The specific results that contributed to the significance of the ExMxAxD effect from this perspective, may be noted by referring to Figure 13. Notice that the low discrimination group did not conform to the general pattern of increasing asymmetry with increases in age. While both the 7-8 and 9-10 year-old subjects showed a right-ear preference for both kinds of material, the 11-12 year-old subjects showed virtually no ear asymmetry for either material.

Although these variations from the general pattern of results were not anticipated, they appear to warrant some attempt at explanation. Yet a different way to illustrate the effects of the quadruple interaction is to plot the speech-sound discrimination means for each of the nine groups against the ear preference percentages obtained with each type of stimulus material. The result is illustrated in Figure 17. With consonant-varied material, a quadratic relationship is evident, right-ear preference decreasing and then increasing with speech-sound discrimination performance. With vowel-varied material, a small right-ear preference changes to a large left-ear preference with increasing levels of speech-sound discrimination.

If a simple positive relationship existed between speech-sound discrimination and magnitude of ear asymmetry, one would be able

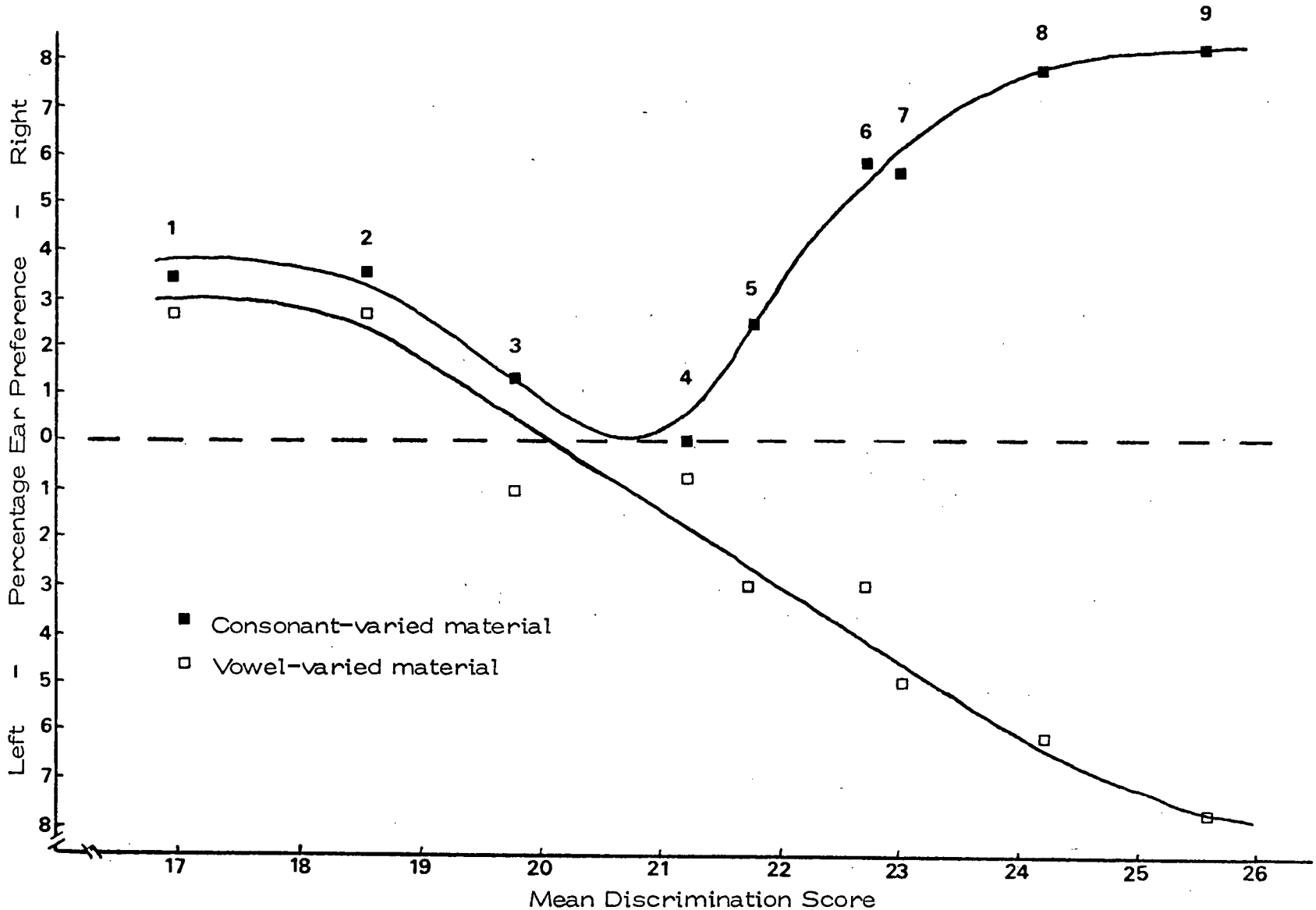

Fig. 17. Relationship of ear asymmetry to speech-sound discrimination in terms of both degree and direction of ear preference. The nine groups are ordered with respect to mean discrimination scores.

to predict speech-sound discrimination scores from knowledge of the degree of asymmetry alone. From examining the data as illustrated in Figure 17, it is evident that an additional factor is required to make this prediction — the direction of ear asymmetry with vowel-varied material. For example, notice that Groups 1 and 5 yield similar magnitudes of ear asymmetries (averaging 2.85% and 2.93% respectively). Yet the speech-sound discrimination performance of the subjects in Group 1 is markedly inferior to that of the subjects in Group 5. If the mean discrimination scores are translated to mean discrimination errors, the subjects in Group 1 make over 60% more errors than the subjects in Group 5. The factor that differentiates these two groups is not the degree of asymmetry, but the direction of ear asymmetry with vowel-varied material. The low discrimination group (Group 1) yielded a right-ear advantage for vowel-varied material, while the middle discrimination group (Group 5) yielded a left-ear advantage for vowel-varied material. As was noted previously, the right-ear versus left-ear recognition of vowel-varied material for subjects in the two low discrimination groups was significant at the .05 level ($F = 4.93$; $df = 1,351$).

Thus the relationship between ear asymmetry and speech-sound

discrimination cannot be described in terms of degree of ear asymmetry alone, as was expected. What must also be taken into account is the direction of ear asymmetry with vowel-varied material. An understanding of the relationship between ear asymmetry and speech-sound discrimination (as well as an understanding of the quadruple interaction) would appear to depend largely upon an understanding of the meaning of these two factors, i.e., the magnitude of ear asymmetry, and the direction of asymmetry for vowel-varied material.

The first factor — magnitude of ear asymmetry — has been generally taken to reflect the degree of hemispheric lateralization for the processing of encoded cues. The evidence for this relationship was discussed above with respect to the necessary and sufficient conditions required to produce ear asymmetry. Evidence for this relationship was also noted in terms of the correspondence between magnitude of ear asymmetry and other reliable indicators of hemispheric asymmetry for language. The present data suggest that, in general, increased lateralization of speech processing is associated with increased speech-sound discrimination ability.

The second factor is represented by the direction of ear asymmetry with vowel-varied material — a phenomenon shown to be relatively sensitive to 'task' or 'set' variables. Presumably this variability is due to the fact that there are more cues relative to the

identification of vowel-varied material than just the encoded ones. When the encoded cues (i.e., transitional formants) are made salient by the task or 'set' involved, recognition of vowel-varied material typically yields a right-ear advantage (Goodglass, 1973; Haggard, 1971; Spellacy & Blumstein, 1970; Weiss & House, 1971). When the nonencoded cues (e.g., duration, steady-state frequency) are made the more salient by task or 'set' manipulation, recognition of vowel-varied material typically yields a left-ear advantage (Neufeld, 1971; Spellacy & Blumstein, 1970). The nonverbal stimuli included in the dichotic tape in the present experiment were expected to result in the selection of the nonencoded cues as the more salient attributes for identification. The right-ear superiority shown for subjects in the two low discrimination groups with the vowel-varied material suggests that they used the same cues to identify both sets of material. That is, it may be that these subjects identified the vowel-varied material on the basis of the encoded attributes, perhaps ignoring or failing to differentiate the nonencoded attributes that were relevant to the task. This apparent failure to utilize the nonencoded cues in the dichotic task is related to poor speech-sound discrimination. That is, the subjects yielding a right-ear advantage for vowel-varied material performed most poorly on the speech-sound discrimination task. The assumption that some subjects fail to use the

nonencoded attributes of the speech signal yields two implications: (1) they would be expected to show a right-ear advantage on vowel-varied material; and (2) this tendency to differentiate among speech sounds only on the basis of one set of cues (i.e., encoded attributes) would be expected to lead to poorer performance on the speech-sound discrimination task relative to the performance of those subjects who use both sets of cues (i.e., nonencoded as well as encoded attributes).

It would appear from the data in Figure 12 that the factor having to do with cue utilization is sensitive to the effects of age. The right-ear advantage for vowel-varied material occurs for the younger age levels only. The pattern of results for the oldest age group suggests that they differentially used the two sets of cues. That is, they appear to have used the encoded features to identify the consonant-varied material and the nonencoded features to identify the vowel-varied material. For subjects in whom this ability to distinguish between the consonant-varied and vowel-varied material is fully developed, the relationship between ear asymmetry and speech-sound discrimination is a simple positive one.

The independent effects of these two factors (i.e., the cue-utilization factor and the speech-lateralization factor) on speech-sound discrimination performance would seem to be fairly straightforward. Failure to utilize the nonencoded attributes of the speech

signal might be expected to interfere with speech-sound discrimination. This would explain the inferiority in discrimination performance of those subjects yielding a right-ear advantage for vowel-varied material relative to that of those yielding a left-ear advantage. This relationship holds regardless of the magnitude of ear asymmetry obtained. On the other hand, the specialization of the left-hemisphere for speech processing might be expected to facilitate speech-sound discrimination. This would explain the positive relationship between ear asymmetry and speech-sound discrimination for subjects yielding a left-ear advantage for vowel-varied material.

It does not seem possible on the basis of these two considerations alone, however, to explain the decrease in speech-sound discrimination with increasing magnitude of ear asymmetry for subjects failing to yield a significant left-ear advantage for vowel-varied material. The interactive effects of the direction and degree of ear asymmetry on speech-sound discrimination are suggested by the data in Figure 17. For subjects failing to yield a significant left-ear advantage for vowel-varied material, the relationship of degree of laterality and speech-sound discrimination is an inverse one. That is, increasing degrees of asymmetry are associated with a successive decrease in speech-sound discrimination performance. Thus, while speech-sound discrimination decreases successively across Groups 4 to 1,

there is a general increase in magnitude of ear asymmetry — from an average of 0.35% in Group 4 to 2.85% in Group 1.

Assuming that the magnitude of asymmetry reflects the development of a linguistic mechanism in the left hemisphere for the perception of encoded cues, and that the direction of asymmetry with vowel-varied material reflects the use or nonuse of the nonencoded cues, the negative relationship between speech-sound discrimination and magnitude of ear asymmetry would be described as follows. For subjects failing to differentiate among speech sounds on the basis of the nonencoded attributes, increasing specialization for the perception of the encoded attributes is associated with increasing decrements in speech-sound discrimination. That is, the greater the specialization in the perception of encoded cues, the greater the decrement in speech-sound discrimination for these subjects.

The explanation for this negative relationship is not readily apparent. One possible explanation would implicate attentional mechanisms. It seems conceivable that increased specialization in the perception of encoded cues may also be associated with increased emphasis and attention to these attributes in the speech signal. If this is so, then the inverse relationship between degree of ear asymmetry and speech-sound discrimination for these stubjects might reflect their increasing failure to differentiate among speech sounds on the basis of the

nonencoded attributes. It would appear that further understanding of the phenomenon may have to await more intensive investigation.

The combined influence of these two factors (the degree of asymmetry, and the direction of asymmetry with vowel-varied material) on speech-sound discrimination performance is illustrated in Figure 18. The degree of asymmetry for each group was calculated by adding the right versus left ear differences for each material, dividing by the total recognition scores across ears and material, and multiplying by one hundred. As illustrated in this figure, the direction of the relationship between magnitude of ear asymmetry and speech-sound discrimination depends on the direction of asymmetry with vowel-varied material. This factor is presumed to reflect the degree of differentiation between the encoded and nonencoded cues of the speech signal. If subjects fail to utilize the nonencoded cues, there is a decrement in speech-sound discrimination, and this decrement increases with degree of ear asymmetry. On the other hand if subjects are differentiating between the nonencoded and encoded cues, speech-sound discrimination increases with degree of asymmetry.

Implications with Respect to the Reading Process

To the degree that speech-sound discrimination is involved in the reading process, ear asymmetry and (by inference) the cerebral

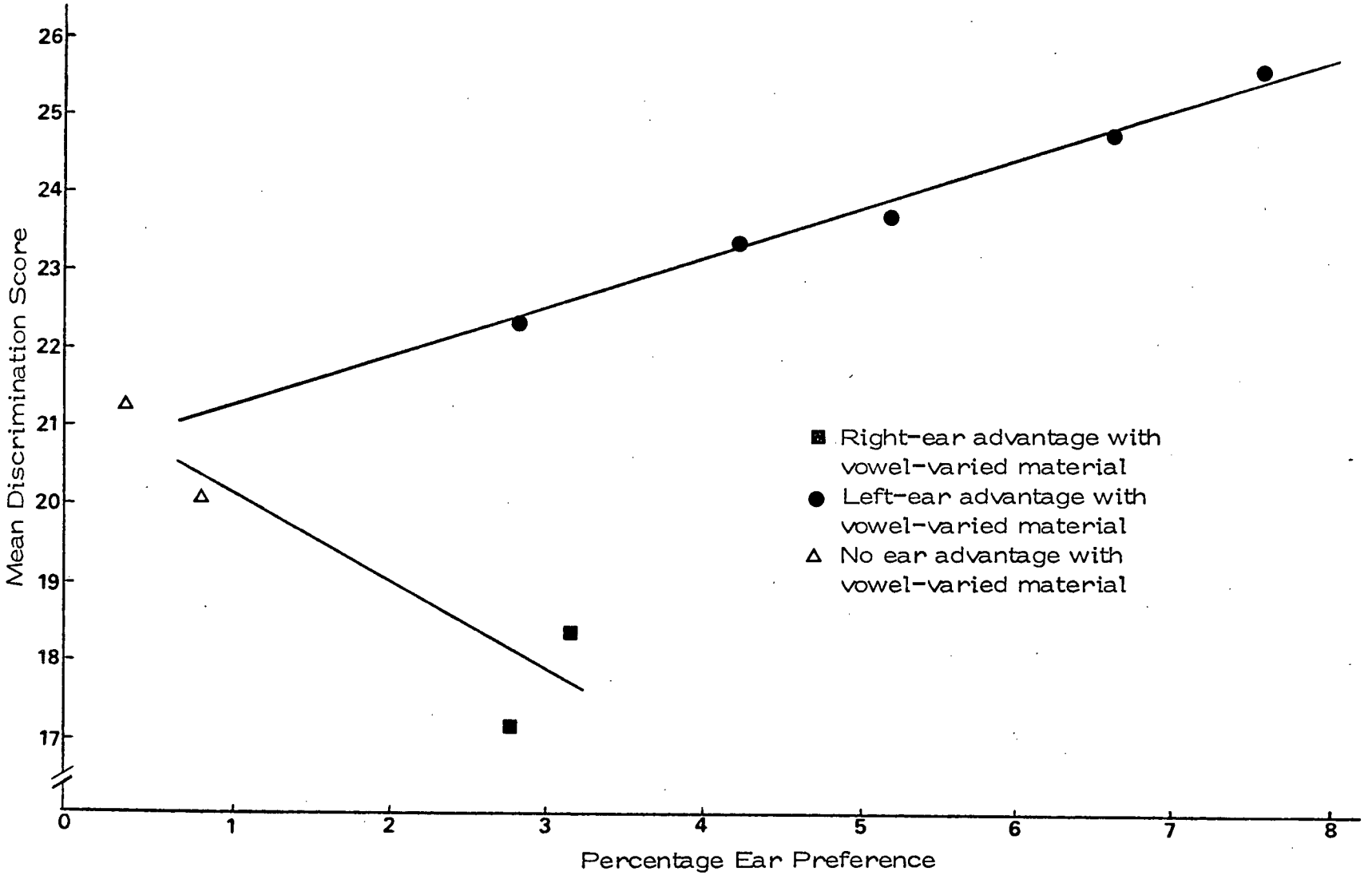

Fig. 18. Relationship of speech-sound discrimination to the degree of ear asymmetry, and the direction of asymmetry with vowel-varied material.

lateralization of language processes are also intimately involved. The rationale for this relationship proceeds as follows: the greater the degree of ear asymmetry and by inference, the greater the lateralization and specialization of the perceptual processing of speech, the greater the ability to discriminate speech sounds, and as this is commonly assumed to be an integral component skill of the reading process, the greater the ability to read.

It is the unexpected discovery of a variation from the general relationship, however, that would seem to involve the most significant implications with respect to the reading process. If it is assumed that there is a direct relationship between reading ability and speech-sound discrimination, then the present data suggest that a positive relationship between laterality and reading ability holds only for subjects who tend to utilize the nonencoded cues of the speech signal. Failure to utilize these nonencoded cues would appear to be a more important determinant of reading difficulty than would lack of asymmetry. In fact, on the basis of the present data, a negative relationship between reading ability and degree of ear asymmetry would be predicted for subjects who are not able to utilize the nonencoded cues. And as this factor is age related, the younger the subjects, the greater the probability of finding evidence of this negative relationship. On the other hand, for older age levels, one would expect a positive

relationship between degree of ear asymmetry and reading ability.

Of the studies discussed above concerning the relationship between ear asymmetry and reading ability, only the study by Satz, Rardin, and Ross (1971) contains information relevant to this proposition. This study involved subjects from both the 7-8 age level and the 11-12 age level, classified as good or poor readers. At the 7-8 age level, there were no differences in degree of asymmetry between good and poor readers. This finding is consistent with the present results, in that degree of asymmetry was not directly related to speech-sound discrimination for this age group. In the 11-12 age level, however, good readers demonstrated a greater degree of ear asymmetry than did poor readers. This positive relationship between reading and degree of ear asymmetry for 11-12 year old subjects would be predicted on the basis of a positive relationship between asymmetry and speech-sound discrimination for this age level.

Indirect evidence of the interactive effects of the two factors on the reading process also comes from a monaural stimulation study relating ear asymmetry to reading ability (Bakker, Smink & Reitsma, 1973). Forty 7-7 1/2 year-old subjects were compared to 38 nine year-old subjects in terms of the relationship of reading ability and degree of asymmetry. A negative relationship was found between degree of asymmetry and reading ability for the younger subjects,

while a positive relationship was found in the case of the older subjects. As the young subjects were even younger than the ones used in the present experiment, it would follow that they would be even less likely to use the nonencoded speech cues in the reading material, and thus would show a negative relationship between degree of asymmetry and reading ability. Bakker et al. state that "a too advanced lateralization seems to hamper rather than to promote efficiency in early reading" (p.309). This argument would appear to be incomplete in the light of the present data. Advanced asymmetry appears to lead to decrements in speech-sound discrimination only when subjects fail to utilize the nonencoded speech cues present in the speech signal. Thus, for younger subjects, the crucial variable would appear to be the inability to use the nonencoded attributes of the stimuli rather than the degree of asymmetry present. Conversely, at higher age levels, the magnitude of asymmetry would be a greater contributing factor to reading ability.

Any application of the present findings to the area of remedial reading must be based on the assumption of a direct relationship between reading ability and speech-sound discrimination. If this assumption is correct, the potential implications of the present study for remedial reading programs would depend largely upon: (1) the reasons for the apparent failure of subjects with low speech-

sound discrimination ability to utilize the nonencoded cues of the speech signal; and (2) the sensitivity of this factor to the effects of learning and experience. As information concerning these questions must await further investigation, only speculation concerning the mechanisms involved and suggestions for further exploration are warranted.

One possible explanation of the failure of some subjects to use the nonencoded cues would be an inability to differentiate these cues in the speech-signal. Or, if discrimination is possible, it may be that the difficulty is related to the 'selection' of appropriate cues. Such attentional factors have been frequently implicated in connection with reading problems (Ackerman, Peters & Dykman, 1971; Hunter & Johnson, 1971; Lasky & Tobin, 1973; Levine & Fuller, 1972), and could conceivably account for the present findings. Although knowledge of the mechanisms involved would contribute much to an understanding of the phenomenon, perhaps of even greater practical importance for remedial reading programs would be knowledge concerning the sensitivity of this factor to learning and experience.

In comparison to the degree of asymmetry factor, which appears to have close correspondence with hemispheric laterality for language functions, the ability to utilize nonencoded speech cues might be expected to be much more experientially based. The capacity for making

discriminations among stimuli and responding to them selectively certainly increases with experience and learning. If the utilization of nonencoded speech cues was shown to be sensitive to learning, this could conceivably be an important consideration in the development of remedial reading programs. One way of testing the sensitivity to the effects of learning would be to reinforce differentially the discrimination of CVC nonsense syllables on the basis of nonencoded cues for subjects showing a deficit in this ability. Effects of learning could be assessed in terms of an increase in appropriate responding over trials. Also, it may be of interest to note whether this training results in a consequent change in the direction of asymmetry for vowel-varied material in a paradigm similar to the one used in the present study. Further investigation, of course, would be required to assess corresponding changes in speech-sound discrimination and reading ability before application could be made to remedial reading programs.

In general, the results of the present investigation support the hypothesis of a positive relationship between ear asymmetry (and by inference, left-hemisphere specialization for speech) and the ability to discriminate speech sounds. However, instead of a simple positive relationship between magnitude of ear asymmetry and speech-sound discrimination as was expected, speech-sound discrimination was also found to vary with the degree of asymmetry obtained with

vowel-varied material. This asymmetry-direction factor was interpreted as reflecting the ability or inability to utilize the nonencoded cues of the speech signal. The data were consistent with the unilateral dominance model of hemispheric relations. Thus the common assumption of a specialization in the right hemisphere for functions involved in left-ear advantages was deemed inappropriate and unnecessary.

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