DEVELOPMENT OF EAR ASYMMETRIES IN DICHOTIC LISTENING

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Abstract

Two hundred and eight Ss from grades 2, 4, and 6 were tested for recognition of dichotically presented musical stimuli, sound effects, and CVC nonsense syllables differing in medial vowel or initial stop consonant. Ear asymmetry was found to increase from grade 2 to grade 6. The left-ear advantage found for music, sound effects, and vowel-varied stimuli was due to decreasing right-ear performance with age. A right-ear advantage for consonants was the result of increasing right-ear performance and a simultaneous decrease in left-ear performance with age. 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.

Sex differences were found in the development of ear asymmetry, girls showing ear asymmetry earlier than boys in the recognition of verbal material and boys showing ear asymmetry earlier than girls in the recognition of sound effects.

The results of the study were compared with those of a similar study using adults as Ss. The comparison showed that substantially larger ear asymmetries were obtained with grade 6 Ss than with adults. This difference was found to be due to the children's inferior recognition of stimuli presented to the nonpreferred ear, preferred ear performance being the same for both groups. The possibility of a covert order of report factor influencing the magnitude of the ear asymmetry found was suggested.

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CHAPTER I

Lateral Asymmetries in Dichotic Listening: A Review

In general, it has been found that under conditions of dichotic[1] stimulation, an ear preference is typically shown in the recognition and recall of some kinds of auditory stimuli. There have been several alternative hypotheses proposed as to the mechanisms involved as well as the conditions necessary to produce these effects. It is hoped that the study described in this paper will contribute to the understanding of ear asymmetries, especially in regard to its development and the little understood left-ear advantage phenomenon.

To provide the rationale for the experiment, a brief review of the relevant literature will be presented as well as a review of the mechanisms that have been proposed to account for the findings. A separate chapter will be devoted to a survey of studies that have provided a detailed analysis of the speech signal in an attempt to discover the minimal conditions required to produce the phenomenon of ear asymmetry.

The Establishment of the Phenomenon

The procedure most frequently used in dichotic listening experiments was introduced by Broadbent (1954) to examine the limits of immediate memory on two separate channels. In his experiment, pairs of digits

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[1]Licklider (1953, p. 1026) defines <u>monotic</u> as the stimulus applied to only one ear at a time, <u>diotic</u> as one stimulus applied simultaneously to both ears, and <u>dichotic</u> as different stimuli applied simultaneously, one to each ear. This usage will be observed here.

were recorded with one digit on each track of a two-channel tape-recorder, and presented to the subjects through stereophonic earphones. The two digits in each pair were recorded in such a way that they began simultaneously. In his most typical condition, a group of three pairs of stimuli were presented on each trial, after which the subject reported all the numbers he heard in any order he chose. Broadbent discovered that if the material was presented fairly rapidly, the subject tended to give all the numbers from one ear before reporting any from the other.

Kimura (1961b) was apparently the first investigator to relate dichotic listening performance to ear laterality effects. Using Broadbent's dichotic digits task, she found that normal right-handed subjects reported digits presented to the right ear more accurately than they did digits presented to the left ear. She attributed the effect to the functional prepotency of the contralateral pathway from the right ear to the language dominant left hemisphere. Thus, the stimulus from a dichotically presented pair which enters the ear contralateral to the hemisphere dominant for language is more likely to be reported correctly than is the stimulus which enters the ipsilateral ear.

Ear Asymmetries with Speech Stimuli

Since Kimura's original report, various investigators have accumulated an impressive body of evidence that the ear advantage obtained in dichotic listening tasks is a real one. Several experimenters have replicated Kimura's finding using Broadbent's dichotic digits task or some modification of it (Bartz, Satz, Fennel & Lally, 1967; Bryden, 1963, 1970; Dirks, 1964; Kimura, 1963; Knox & Kimura, 1970). Broadbent and Gregory (1964) have also obtained a right-ear superiority using a multiple-choice recognition paradigm rather than a free recall paradigm. Following the dichotic presentation of three pairs of digits, four groups of three digits were presented diotically at the same rate, two of which corresponded to the digits presented dichotically. The task was to choose these two triads.

The laterality effect has been obtained with speech stimuli other than digits. Most of these experiments have used Broadbent's paradigm, only substituting alternative stimuli for digits. With this type of procedure, a right-ear advantage has been obtained with monosyllabic words (Curry, 1967; Curry & Rutherford, 1967), two syllable words (Bartz et al., 1967), and nonsense syllables (Curry, 1967; Curry & Rutherford, 1967; Kimura, 1967). Borkowski, Spreen & Stutz (1965) found the result using monosyllable nouns matched for initial phoneme. This was replicated by Jones & Spreen (1967) using as subjects educable retarded children of six to twelvee years of age. Using only one pair of words per trial, Dirks (1964) obtained a right-ear advantage in a free recall paradigm, as did Knox & Kimura (1970) using monosyllable concrete nouns in an object identification paradigm. Using a multiple-choice recognition procedure with one dichotic pair per trial, Kimura (1967) obtained a right-ear advantage with trisyllabic nonsense syllables, and Kimura & Folb (1968) found it with these trisyllabic nonsense syllables inverted, i.e., backwards speech.

Several investigators have reported similar effects in tasks which are very different from the digits test and its modifications. In an experiment reported by Oxbury, Oxbury & Gardiner (1967), subjects repeated a continuous string of digits presented to one ear while trying to ignore digits presented to the other ear. Irrelevant digits were paired with 25 or 50 percent of the attended digits. Errors were more frequent when the left ear was the attended ear. Treisman & Geffen (1967) presented two messages dichotically and asked subjects to tap to target words in either channel while shadowing one of the channels. When the right ear was shadowed, more words were correctly repeated. Corballis (1967) presented digits three at a time. Two digits were presented one to each ear, and a third was presented to both ears. Right-ear responding was more accurate than was left-ear responding. A significance test for this effect was not reported however. Studies splitting up the speech signal have also resulted in right-ear superiorities. These studies will be discussed in the following chapter.

Ear Asymmetries with Non-Speech Stimuli

A similar phenomenon has been discovered with various nonverbal stimuli. With these stimuli, however, the ear advantage is reversed, identification of stimuli presented to the left ear being superior to identification of stimuli presented to the right ear. Kimura (1964) presented unfamiliar woodwind solo passages dichotically to right-handed subjects in a multiple-choice recognition paradigm and obtained significantly higher recognition scores for the left ear. The same subjects showed right-ear superiority in the dichotic digits test. This discovery was related to Milner's (1962) finding of more severe decrements in right-temporal lobectomized patients than in left-temporal lobectomized patients on all subtests of the Seashore Measures of Musical Talents. The most severe decrements were on the Tonal Memory (recognizing patterned sequences of tones) and Timbre (tone quality) subtests. Shankweiler (1966) found a similar deficit in the ability of right-temporal lobectomized patients to recognize familiar melodies. Subsequently, Kimura (1967) obtained a left-ear advantage where subjects were asked to sing dichotically presented familiar and unfamiliar melodies.

In an attempt to isolate the components of music that are critical in the demonstration of an ear preference, Spellacy (1970) presented music and three types of musical components - temporal patterns, frequency patterns, and timbre in a simple recognition paradigm, but found a significant left-ear preference only for the complex music stimuli. A similar study by Spreen, Spellacy and Reid (1970) replicated the left-ear advantage for music and also found a significant left-ear preference for tonal patterns. Darwin (1969b), using pure tone sequences to form a melodic line, also obtained a left-ear advantage.

Left-ear superiorities have also been found in other nonspeech tasks. In a study by Chaney & Webster (1966), subjects showed a left-ear superiority in identifying dichotically presented sonar signals. The same subjects who were found by Curry (1967) to be more accurate with the right ear in recalling dichotically presented words and nonsense syllables were better with the left ear when identifying familiar environmental sounds presented dichotically. A left-ear superiority for sounds made by familiar objects was also found by Kimura & Knox (1970) for the subjects who had shown a right-ear advantage for digits and nouns.

On the basis of the data discussed above, it would appear that in general, subjects tend to be more accurate in identifying verbal stimuli presented to the right ear, and nonverbal stimuli presented to the left ear in dichotic listening tasks.

Proposed Mechanisms

Relation of Ear Asymmetry to Cerebral Dominance

The evidence that the right-ear advantage in dichotic listening is related to hemispheric dominance is fairly strong. Most compelling are data from a study by Kimura (1961a) which involved two groups of epileptic patients as subjects. A group of 107 patients who presumably were left-hemisphere dominant for language produced averages of 86.5 and 79.8 percent correct responses for digits presented to the right and left ear respectively. But a group of 13 patients who were right-hemisphere dominant (as determined by the Wada sodium amytal test) were 88.5 percent accurate on left ear stimuli and only 78.0 percent 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 and from subjects with speech represented in the right hemisphere, is independent of the location of the patient's epileptogenic focus.

Subjects which allow comparisons of right-handed and left-handed subjects are also relevant to the hypothesis of a relationship between cerebral dominance and ear asymmetry, but must be interpreted with some caution. The relation between hand preference and cerebral dominance for language in right-handed subjects is straightforward; over 90 percent of a random sample of right-handed subjects can be expected to be left-brained for language (Benton, 1965; Milner, Branch & Rasmussen, 1964). Most of the published studies of dichotic listening have used right-handed subjects exclusively, and these studies almost invariably have resulted in right-ear superiority. What one would predict for left-handed subjects is not so clear, however. Evidence indicates that only about two-thirds of normal left-handed subjects have left-hemisphere language dominance and that left-handed subjects as a group tend to be less strongly lateralized than right-handed subjects, regardless of which side is dominant (Benton, 1965; Milner et al., 1964). Both these differences might be expected to lead to less pronounced right-ear superiorities when groups of left-handed subjects are studied in dichotic listening tasks using verbal material. The few studies which have compared performance of right-and left-handed subjects on dichotic listening tasks have found strong right-ear superiority in right-handed subjects, and less marked right-ear superiority (Bryden, 1970; Curry, 1967; Satz, Achenbach, Pattishal & Fennel, 1965) or no ear superiority (Bryden, 1965; Zurif & Bryden, 1969) in left-handed subjects. There is some evidence that familial left-handed subjects are more likely to be right-hemisphere dominant for language than the non-familial left-handed (Weinstein & Sersen, 1961) and that familial left-handed subjects are much more likely to show left-ear superiority in the dichotic listening situation than either right-handed or non-familial left-handed subjects (Bryden, 1967, 1970; Curry, 1967; Zurif & Bryden, 1969).

On the basis of such evidence, most authors have accepted as probable a relationship between cerebral dominance for language and the occurrence of right-ear advantages with verbal material. They have not, however, agreed on the nature of this link. Some attribute it to perception (Kimura, 1961b), some to short-term memory (Inglis, 1965), others to attention (Treisman & Geffen, 1968). Other authors have chosen to explain ear asymmetries without reference to cerebral dominance. It is to their explanation that we will turn first.

The Response-Bias Hypothesis

Attempts have been made to explain the ear difference effect by claiming that there is a general tendency to report material entering the right ear before that entering the left, implicitly denying the stimulus specificity of the direction of the effect (Oxbury, Oxbury & Gardiner, 1967). Several investigators have observed that information presented to the ear reported first (immediate or perceptual channel) is more accurately recalled than information presented to the ear reported second (delayed or storage channel) (Broadbent, 1958; Bryden, 1964; Inglis, 1965). If subjects therefore, in a free recall task tend to report more often from the right ear first, an ear asymmetry in favor of the right ear would be expected because of the failure to control for a bias in the order in which messages are reported.

Although some investigators have indeed observed this order of report phenomenon in favor of the right ear (Bartz et al., 1967; Broadbent, 1954, 1957; Bryden, 1963), the evidence regarding the presence of such a tendency is equivocal. Satz et al., (1965) found a slight tendency for the left ear to be reported first. And Inglis & Ankus (1965) failed to find any consistent tendency for subjects to give the material from the right ear first in a sample ranging in age from 10 to 70 years. It thus appears that the preference for starting the report sequence with an item presented to the right ear is a less universal finding than the overall right-ear superiority.

The response-bias model predicts that all lateral asymmetries will disappear when order of report is taken into account. Several methods have been used in attempts to measure the magnitude of the ear superiority when the response bias is controlled. One statistical method is to score trials on which the first stimulus reported was presented to the right ear separately from trials on which a left-ear stimulus is reported first. Using the dichotic digits task, both Bartz et al., (1967) and Bryden (1967) found the right ear to be significantly more efficient regardless of whether stimuli presented to the right ear or stimuli presented to the left ear were reported first. An alternative method of statistical control is to score separately data from the first reported ear and data from the delayed ear. Comparisons are then made between right and left ears as immediate ear and as delayed ear. Again, both Bartz et al., (1967) and Bryden (1967) found the right ear to be superior as both the immediate and the delayed channel. Satz et al., (1965) found right-ear performance to be somewhat superior when only the data from the ear reported last on a given trial were analyzed, although this difference was not significant ($p < .20$). The results from these studies using statistical controls for possible response-bias effects are not very extensive, but they are consistent in indicating a right-ear superiority.

Another method of determining whether ear advantages can be obtained independently of a response-bias effect is to use an ordered recall procedure in which the subject reports the left ear first on half the trials and the right ear first on half the trials. Bryden (1963) reports a significant right-ear superiority when such controls are used with a dichotic digits task. Borkowski et al., (1965) used this procedure with one-syllable nouns as stimuli and found significant right-ear superiorities in delayed channel comparisons as well as in immediate channel comparisons. Satz et al., (1965) obtained similar results using a four-pair-per-trial digits task.

Also relevant to the evaluation of the response-bias hypothesis are numerous studies which have utilized paradigms that give no opportunity for serial order bias and yet result in significant ear difference effects. These include the studies in which the subject is asked to attend to and report only the stimuli presented to a given ear (Chaney & Webster, 1966; Kirstein & Shankweiler, 1969), studies using a forced-choice recognition procedure (Broadbent & Gregory, 1964; Kimura, 1967; Kimura & Folb, 1968), and studies using a simple "yes-no" recognition paradigm (Spellacy, 1970; Spellacy & Blumstein, 1970; Spreen, Spellacy, & Reid, 1970).

It would seem that there is little evidence to support the hypothesis that laterality effects are due entirely to a response bias. However, it has been demonstrated that order effects do occur and can accentuate left-right differences in dichotic listening in the free-recall procedure.

The Differential-Storage Hypothesis

Inglis (1965) has suggested that the phenomenon of right-ear preference in the recall of verbal stimuli may be explained by a differential storage deficit. According to this hypothesis, input arriving in the dominant hemisphere is less subject to interference or spontaneous decay than is input arriving in the nondominant hemisphere. That is, short-term memory processes may be more efficient in the left hemisphere than in the right. According to this model, lateral asymmetries will increase as a function of time between storage and recall.

When applied to an ordered recall situation, the differential storage model would predict little or no difference between accuracy on the left ear when it is given first and accuracy on the right ear when it is given first. However, with material reported second, recall of stimuli presented to the right ear would be more accurate than recall of stimuli presented to the left ear. Bryden (1967) in a reanalysis of data collected in a previous study (Bryden, 1963) found that there was at least as large a difference between ears on the immediate channel as on the storage channel. Borkowski et al. (1965) found a right-ear superiority of 7 percent on the immediate recall channel and one of 6 percent on the storage channel. Darwin (1969b) has also failed to find evidence that the ear difference effect is any smaller on the first than on the second reported ear. In contrast, Satz et al. (1965) reported a 4 percent difference on the immediate channel and one of 11 percent on the delayed channel, supporting the differential-storage model. Upon closer analysis of this study, however, it appears that the small differences between ears reported on the immediate channel may have been due to the ease of the task resulting in a "ceiling effect." Unless the task is made sufficiently difficult to produce a number of errors on the immediate recall channel, it is obvious that a right-ear superiority will not appear.

The differential-storage hypothesis may also be applied to the simple "yes-no" recognition paradigm introduced by Spellacy (1970). The model would imply that ear asymmetry would increase with longer intervals between the presentation of the dichotic stimulus and the recognition stimulus. Thus, memory decay in the nondominant hemisphere would be minimal at short intervals but increase with longer presentation-recognition intervals. Assuming that the same mechanisms would apply for nonverbal stimuli that are supposedly right-hemisphere dominant, Spellacy (1970) and Spreen, Spellacy & Reid (1970) conducted two studies using the same stimulus materials (music), varying only the length of the interval between the presentation of the dichotic stimulus and the recognition stimulus. Intervals of 1, 5, and 12 seconds were used. It was found that difference between ears is at a maximum immediately after the presentation of the stimulus and tends to decrease gradually with no significant differences occurring with an interval of 12 seconds. Thus the available evidence with the possible exception of Satz et al., (1965) would indicate that the differential-storage hypothesis is untenable.

The Attentional-Bias Hypothesis

Treisman & Geffen (1968) have suggested that the ear difference effect arises because of an unequal distribution of attention, the right ear being easier to attend to than the left ear for verbal material.

The implication is that if attention was controlled, little, if any, ear asymmetry would be obtained. Several of the investigations under discussion have included conditions in which subjects were presumably attending, or at least attempting to attend, to only one ear while stimuli were presented dichotically. In one such study, Dirks (1964) found a significant right-ear superiority when subjects attended to both ears for digits or electronically distorted words as stimuli, but a smaller, non-significant right-ear superiority when subjects attended to only one ear and heard distorted words. These results are consistent with the attentional-bias model. Most of the relevant studies, however, report data which are inconsistent with this model. Kimura (1967), using words and nonsense syllables as stimuli, found with both types of material that the group instructed to report the right ear only performed significantly better than the group instructed to report the left ear only. Also, in the studies by Chaney & Webster (1966), Kirstein & Shankweiler (1969), and Oxbury et al., (1967, Exp. 11), subjects were instructed to attend to and report from only one ear at a time, and right-ear superiorities for verbal stimuli were obtained in each of these studies.

If ear asymmetries were a result of an unequal distribution of attention, a reasonable expectation would be that sounds which are more easily separated by selective attention would show a greater ear difference than those which are more difficult to separate. Kirstein & Shankweiler (1969) however, found that when a subject is asked to report sounds from a particular ear, he makes fewer errors of recall for vowel-contrasted nonsense syllables than for consonant-contrasted nonsense syllables, but in the same experiment, the latter sounds showed a greater right-ear advantage than did the former sounds.

That attention may be a necessary factor for the occurrence of right-ear asymmetries is consistent with either a memory or a perceptual explanation of ear preference. Evidence that both perceptual and attentional factors may be involved in ear asymmetry is discussed in the following chapter. The attention hypothesis by itself, however, is inadequate in accounting for ear asymmetries, especially the reverse asymmetries shown for speech and non-speech stimuli.

The Perceptual Bilateral Dominance Hypothesis

Kimura (1961b) has argued that ear differences in dichotic listening tasks are primarily a perceptual phenomenon. According to this proposal, material arriving at the dominant hemisphere is more readily perceived than material arriving at the nondominant hemisphere. It would appear that this model can best account for the fact that ear asymmetries are obtained with procedures controlling for attention, order of report, and memory factors. The difference, however, between the perceptual model and, for example, the differential-storage model, is very subtle and the differential implications of the two notions are not as distinct as might be desired. According to the perceptual hypothesis, errors of reproduction are due to a failure of part of the input to enter the system. According to the differential-storage hypothesis, these errors of reproduction are due to a decay or distortion of input after it has entered the system. Although a perceptual model does not imply a denial of the effects of short-term memory decay, it does assume that both inputs will decay equally over time. In contrast, the differential-storage model implies that input to the nondominant hemisphere decays at a faster rate than input to the dominant hemisphere. Thus the perceptual model in contrast to the differential-storage model would seem to predict ear asymmetries of the same degree on both the immediate and storage channels. With the possible exception of Satz et al., (1965), the data discussed fulfill this prediction (Borkowski et al., 1965; Bryden, 1967; Darwin, 1969b). For simple recognition procedures, the perceptual model would suggest that the difference between the two channels is at a maximum at short-term intervals with gradual but equal decay of both channels with time. Again, the results of Spellacy (1970) and Spreen et al., (1970) clearly support such a model. Thus the perceptual model appears to be consistent with most of the data in dichotic listening experiments.

Whereas the previously discussed hypotheses have more or less ignored the left-ear advantage phenomenon for certain nonverbal stimuli, Kimura (1967) accounts for it by postulating a right-hemisphere dominance for such material. According to Kimura, the auditory asymmetries reflect the functional asymmetry of the brain for the perception of verbal and nonverbal stimuli. Thus the superior right-ear scores for the perception of verbal material reflect left-hemisphere specialization for language functions, whereas greater left-ear scores for certain nonverbal materials reflect right-hemisphere specialization for nonverbal functions. An alternative explanation for the left-ear advantage phenomenon has been suggested by Spellacy & Blumstein (1970) and will be discussed in detail in the following chapter. It is largely in reference to this question that the present investigation was conducted.

Kimura has based her explanation of perceptual asymmetry on a hypothesized superiority of the contralateral pathway over the ipsilateral pathway in dichotic listening. Thus the right-ear superiority for verbal materials may be brought about by the "superior connections" between the right ear and the contralateral regions in the left hemisphere which are dominant for language. Conversely, the left-ear superiority for nonverbal materials may be a consequence of "superior connections" between the left-ear and the contralateral regions of the right hemisphere dominant for those materials. Kimura suggests that this contralateral prepotency is based upon the greater number of contralateral neurons as well as upon inhibition of ipsilateral neurons during dichotic stimulation.

In regard to her first premise, evidence indicates that the crossed auditory pathways are stronger than the uncrossed pathways in cats and dogs (Rosenzweig, 1951; Tunturi, 1946) and in man (Bocca, Calearo, Cassinar & Migliavacca, 1955; Hall & Goldstein, 1968; Penfield & Rasmussen, 1950). Such a finding suggests that monotic stimulation should also result in ear asymmetries. Significant ear differences have been reported with monotic stimulation (Bakker, 1968, 1970), but many more subjects have been required to reach significance with this procedure.

Corroboration for Kimura's second premise has come from the work of Milner, Taylor & Sperry (1968). The subjects in this study were right-handed patients for whom the main commissures linking the cerebral hemispheres had been sectioned to relieve epilepsy. Under dichotic stimulation, these subjects were able to report verbal stimuli presented to the right ear, but not those presented to the left; under monotic stimulation, they performed equally well with the two ears. Milner et al. attribute the results to suppression of the ipsilateral pathway from left ear to left (language) hemisphere during dichotic stimulation, and, of course, to sectioning of the callosal pathway that otherwise would have carried the left ear input from right hemisphere to left.

Although the data discussed would seem to support a perceptual bilateral dominance model for ear asymmetries in dichotic listening, the evidence is far from complete. Recently a number of studies investigating the nature of cerebral dominance in speech perception have shed further light not only on the conditions necessary to produce a right-ear advantage and thus the mechanisms implicated, but also on the nature of hemispheric relations in reference to ear asymmetries in dichotic listening. It is to these studies that we would now like to turn.

CHAPTER II

Lateralization of the Phonological Processes

To say that a given hemisphere is the dominant hemisphere for language is attributing to that hemisphere a set of characteristics which is only vaguely understood. The present knowledge of the brain mechanisms which underly language in general is miniscule. Presumably as more is known about the conditions necessary to produce right-ear superiorities, more productive questions will be forthcoming as to the mechanisms involved in ear asymmetries and hemispheric relations.

It would, of course, be incorrect to suggest that nothing is known about language processes. One of the things known is that language is heirarchically organized into levels of structure, each of which may be considered more-or-less independently of the others. One such level is that of meaning. The studies already mentioned using nonsense speech and inverted nonsense speech as stimuli demonstrate clearly that a right-ear advantage does not depend upon the stimuli being meaningful (Curry, 1967; Curry & Rutherford, 1967; Kimura, 1967; Kimura & Folb, 1968).

The next logical step first taken by Shankweiler & Studdert-Kennedy (1967) was to pull the speech signal apart and to test its components in order to determine which aspects of the perceptual process depended upon lateralized mechanisms. The stimuli used were synthetic steady-state vowels. The syllables used were all combinations of the stop consonants /b, d, g, p, t, k/ with the vowel /a/. The fifteen possible pairs were presented dichotically, one pair per trial, and the subjects were instructed to report both syllables on each trial, guessing if necessary. A similar procedure was followed with five equal duration (300 msec.)

steady-state vowels (i, ɛ, ae, a, u). A significant right-ear advantage was found for the stop consonants and a small, but nonsignificant right-ear advantage for the vowels.

This right-ear advantage for consonants has been replicated for initial stops (Darwin, 1969a; Haggard & Parkinson, 1971; Kirstein & Shankweiler, 1969; Spellacy & Blumstein, 1970; Studdert-Kennedy & Shankweiler, 1970) and extended to final stops (Darwin, 1969a; Studdert-Kennedy, 1970), fricatives (Darwin, 1971), and laterals and semivowels (Haggard, 1971).

The findings with vowels have been far less consistent. They have shown no ear preference (Darwin, 1969a, 1971), a nonsignificant right-ear advantage (Kirstein & Shankweiler, 1969; Studdert-Kennedy & Shankweiler, 1970), a significant right-ear advantage (Chaney & Webster, 1966; Darwin, 1971; Haggard, 1971; Spellacy & Blumstein, 1970) and a significant left-ear advantage (Spellacy & Blumstein, 1970).

To be able to integrate these results, it is necessary to have some understanding of the relevant stimulus properties of consonants and vowels pertaining to speech perception, as well as a more comprehensive description of the conditions, paradigms, and procedure used in the studies themselves. For the former the interested reader is referred to Liberman, Cooper, Shankweiler & Studdert-Kennedy (1967) and Lindblom & Studdert-Kennedy (1967) although a brief discussion of the relevant aspects of speech will be included here.

Analytically, the sounds of speech form a subset of the sounds of the environment since they are subject to phonetic constraints deriving from the anatomy and physiology of the vocal tract and to phonological and allophonic constraints imposed by particular languages. The phonetic constraints are of two main types, both of which lead to a complex relationship between the perceived phoneme and the acoustic signal. In one case a complex relation arises because the articulatory specifications for some phonemes are incomplete, the articulators which are not specified can then assume a wide variety of positions with a corresponding wide variety of acoustic sequelae. In the second case the complex relation arises from the variation in size and shape of the vocal tract producing the sound. Phonemes which show extensive restructuring of their acoustic cues as a function of context are referred to as "encoded."

Encoding is a property of the stimulus, but it is possible to distinguish it from other types of stimulus properties. Encoding is not defined by any single acoustical correlate, but because the need for the encoding principle appears with the need to move an articulator from one position to another, 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." A vowel is characterized by a relatively stable (approximately 100 msec.) set of values of the resonant frequencies of the vocal tract, the formants. When a consonant is articulated, these frequencies change rapidly (30 to 80 msec.), but the values to which they go are relative to the neighboring vowel, and to the position it is in with respect to that vowel. Thus the consonant is said to be encoded. This variance is different for each cue of manner, voicing and place.

The perception of steady-state and isolated vowels is quite different from the perception of most consonants, depending primarily on the frequency position of the formants. There is, for these vowels, no restructuring of the kind found to be so common among the consonant cues and, accordingly, no problem of invariance between acoustic signal and perception. Therefore, steady-state vowels are said to be unencoded. However, vowels are rarely steady state in normal speech. Most commonly these phonemes are articulated between consonants and at rather rapid rates. Under these conditions vowels do show substantial restructuring - that is, the acoustic signal at no point corresponds to the vowel alone, but rather shows at any instant, the merged influences of the preceding or following consonant. Thus the speech signal typically does not contain segments corresponding to the discrete and commutable phonemes. The formant transition is, at every instant, providing information about the two phonemes, the consonant and the vowel - that is, the phonemes are being transmitted in parallel.

The dichotic listening paradigm seems especially suited to teasing out the conditions necessary for a right-ear advantage. Liberman et al. (1967) hypothesized that only those aspects of speech which show appreciable contextual variation (i.e. the encoded aspects) would give a right-ear advantage. This category would indicate those sounds containing formant transitions. This hypothesis is certainly consistent with Shankweiler & Studdert-Kennedy's (1967) discovery of a right-ear preference for synthetic isolated steady-state vowels. This right-ear advantage for synthetic initial stops has been replicated by Haggard & Parkinson (1971) who used the same procedure as Shankweiler & Studdert-Kennedy (1967) for the stops /b, p, d, t/, and also by Kirstein & Shankweiler (1969) who used an attention paradigm where the subject is instructed to preattend and report from only one ear in a given block of the experiment. Using a one-pair-per-trial free recall procedure, Darwin (1969a) replicated the right-ear advantage finding with synthetic initial stops and extended the finding to final stops in vowel-consonant (VC) syllables, using a special method of scoring to control for order of report. Studdert-Kennedy & Shankweiler (1970) repeated their initial experiment using real speech and again found right-ear superiorities for both initial and final stops incorporated into CVC syllables. Spellacy & Blumstein (1970) used a novel recognition paradigm in which, four seconds after each dichotic stimulus pair, the subject was presented with a diotic recognition foil which he was to identify as being the same as or different from the members of the preceding dichotic pair. Again, a right-ear preference was obtained for initial stops in CVC syllables. The results of these studies are not inconsistent with the notion that contextual variation is an important factor in the production of a right-ear preference for verbal material.

In a more direct test as to the necessity of contextual variation in producing a right-ear advantage, Darwin (1971) used fricatives as opposed to stop consonants. There are two main cues which contribute to the perception of fricatives. The first, and perceptually the most significant, is the spectral peak of the friction itself. This peak shows relatively little variation with vowel context. A secondary cue is the formant transition to adjacent vowels. These transitions show much more contextual variation with vowel context than do the spectral peaks, as they depend on the shape of the whole vocal tract. Darwin used the six fricatives /f, s, ʃ, v, z, ʒ/ in the syllabic frame /-ɛp/, employing the one-pair-per-trial free recall procedure. 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 firction. Although fricatives synthesized from friction alone, without the formant transitions, were clearly identifiable, only the two conditions which included the formant transitions showed a right-ear advantage, thus supporting the hypothesis of Liberman et al.

As was mentioned above, this hypothesis also seems to provide an account of the fact that Shankweiler & Studdert-Kennedy (1967) found no significant ear advantage with synthetic isolated steady-state vowels. This finding however, would be consistent with several other plausible hypotheses, including variations of the contextual variation hypothesis of Liberman et al., as well as other completely independent hypotheses. One possibility is that right-ear superiority depends primarily upon preferential processing in one hemisphere of certain purely acoustical properties that are present in stop consonants but lacking in vowels. A second possibility is that the right-ear advantage depends critically upon the presence of an encoded acoustical feature in the stimulus that is present in stop consonants and lacking in steady-state vowels. A third possibility is that a right-ear preference is dependent upon the actual "perceptual load" of decoding, this load being greater in stop consonants than in vowels. A further alternative is that right-ear superiority depends only upon the phoneme class distinguishing the response items and not upon stimulus properties, vowels being among the classes not showing a right-ear advantage. Halwes (1969) on the other hand entertained the possibility that where vowels are used as stimuli, a right-ear advantage is perhaps masked by a ceiling effect. It was pointed out that in Shankweiler & Studdert-Kennedy's (1967) experiment, vowel identification proved to be a much easier task than is consonant identification.

Investigations by Kirstein & Shankweiler (1969) using the attention paradigm described earlier, and by Darwin (1969a) using the one-pair-per-trial free recall procedure, also failed to obtain significant ear differences for synthetic steady-state vowels, giving general support to the above hypotheses. A previous experiment by Chaney & Webster (1966) had shown a significant right-ear advantage for steady-state vowels, but the lack of adequate controls for channel differences, and the complex procedure in which the subjects were instructed to identify the sound as regards to sex of author, inflection, voice, and ear, render the results difficult to interpret in reference to the various hypotheses.

One of the main purposes of a second study by Studdert-Kennedy & Shankweiler (1970) was to determine whether natural vowels embedded in a consonantal frame would show a greater right-ear advantage than the synthetic, isolated, steady-state vowels of the previous study, thus supporting a contextual variation hypothesis or a modification of it. Although a significant right-ear superiority was not obtained, some tendency toward a right-ear advantage for the vowels was evident. The negative findings were explained by a consideration of the fact that these vowels were approximately 300 to 500 msec. long whereas in natural speech they average only 100 msec. According to Liberman et al. (1967), the acoustic cues for vowels in slow articulation tend to be invariant. Thus the results of this experiment again appear inconclusive.

One attempt to clarify the issue was made by Haggard (1971, Exp.I) using semivowels and laterals (w, r, l, j). Of all classes of speech sounds, the semivowels and laterals are those which vowels have most in common. These sounds are made with a relatively open vocal tract, and have a short steady state which is acoustically similar to a vowel. But they also have formant transitions leading into the neighboring vowel. In the latter respect, they are analagous to stop consonants, but the transitions are slower and more intense, being made with a more open vocal tract. The words "what, rot, lot, yacht" were used in a one-pair-per-trial free recall procedure. Right-ear superiorities very similar to those found by Shankweiler & Studdert-Kennedy (1967) for stop consonants were obtained. These results suggest very strongly that properties shared between vowels and semivowels such as overall duration and openess of vocal tract are not relevant to right-ear superiority and that some properties shared by semivowels and stop consonants such as the common presence of formant transitions and encoding are relevant. The finding that the most plausible acoustical factor is irrelevant sheds doubt on the hypothesis that right-ear superiority in dichotic listening tasks depends primarily upon acoustical processing.

Normally, the source of encoding for vowels is the consonantal context. This encoding is usually reflected in the formant transitions, thus making it difficult to separate these two factors in regard to their relative importance in the production of a right-ear effect. Haggard (1971, Exp. II) used a novel technique to divorce encoding as an explanatory principle from the stimulus properties of formant transitions. This was done by using speaker context as a special source of encoding not involving formant transitons. Synthetic steady-state vowels were embedded in CVC syllables, creating the words "a kid, a ked, a cud, a cod, a could." These stimuli were recorded in two different fundamental frequencies similar to a high voice and a low voice. A right-ear preference was found, demonstrating that the addition of an element of encoding to steady-state vowels is a sufficient condition for this effect. Thus the idea that right-ear superiority depends upon a property of a phoneme class was ruled out. Also, an analysis of sequential effects showed that the amount of decoding actually required on a given trial was not relevant. The results would seem to indicate that a sufficient condition for the emergence of a right-ear advantage is the presence of some normally encoded acoustical attribute.

The above results were essentially replicated by Darwin (1971) with synthetic steady-state vowels in the words "a nit, a net, a gnat, a knot, a nut." Each stimulus was produced by two different sized vocal tracts, providing a source of contextual variation. A control condition was included wherein only sounds from the smaller vocal tract were presented. The results were the same as those of Haggard (1971) with the additional finding that the right-ear superiority with vowels depended upon the nature of the discrimination within the framework of the whole experiment rather than within an individual trial. Although no ear advantage was demonstrated by the control group, the same stimuli presented to the experimental group demonstrated right-ear superiority. Here, then, it is not merely the extraction of the encoded acoustical cue which is important but also its phonetic relevance.

The implication is that the presence of some normally encoded acoustical attribute does or does not produce a right-ear advantage, depending upon the nature of the task, and the relevance of that attribute to the task. Support for this hypothesis comes from experiments dissociating the particular stimulus feature encoded from the task involved. One such experiment by Darwin (1969b) involved inflecting the fundamental frequency on a high quality synthesized syllable. The study demonstrated that these simple pitch sweeps give a left-ear advantage even though they are carried on a word. These pitch sweeps did not cue a phonemic distinction. That the stimulus parameter of fundamental frequency is not responsible for this finding was demonstrated in a complementary experiment by Haggard & Parkinson (1971, Exp. I). Fundamental frequency was manipulated, being used to cue the linguistic distinction of voicing for stop consonants. A right-ear advantage rather than a left-ear advantage was obtained.

Further support that the presence of an encoded stimulus attribute does not necessarily result in a right-ear advantage comes from a second experiment by Haggard & Parkinson (1971, Exp. II). A series of six sentences, each varying in emotional tone was used as stimuli. An attention paradigm was used with babble as the competing stimulus. The task of the subject was to indicate by ticking a response sheet both the sentence and the emotion heard. Recognition of the emotions showed a left-ear advantage, while there was no ear difference for recognition of sentences. Upon analysis of the data, it was found that in cases where sentences were incorrectly reported, an above chance score was still obtained on emotions, indicating a possible dissociation of the tasks and implicating attention as a possible source for this dissociation. Thus while the experiment supports the idea that the perceptual task is of prime importance in determining ear advantages, it also indicates that the subject's attentional strategy may have an effect upon ear asymmetries.

This attentional factor was directly attacked by Spellacy & Blumstein (1970) who used their recognition paradigm described previously. The stimuli were dichotic pairs of CVC nonsense syllables that differed in medial vowel or initial consonant. The subject's attention was manipulated by creating an expectation of hearing language or nonlanguage sounds. This manipulation was achieved for the language-expectation group by presenting the test stimuli in a random series along with CVC syllables constituting real English words. A nonlanguage set was established in the second group by presenting the test stimuli in series along with melodies and sound effects. The vowels showed a right-ear advantage for the language expectation group and a left-ear advantage for the non-language expectation group, consonants showing a right-ear advantage for both groups.

As discussed above, the encoded cues are the only stimulus properties by which stop consonants may be identified. It would seem consistent with the results of Spellacy & Blumstein (1970) as well as with the previous studies discussed, that any task or attentional strategy that makes this consonant identification relevant will result in a right-ear advantage. On the other hand, if a stimulus possesses attributes by which it may be identified that are both encoded and unencoded, the direction of the ear advantage will be determined by whether or not the subjects have been given a "language set." Thus vowels, possessing both formant transitions and steady-state frequencies, show a right-ear advantage only if the encoded attributes are made relevant to the identification task.

The assumption, that a right-ear advantage depends upon both the presence of some encoded acoustical cue and a task or attentional strategy that makes that encoded property relevant, appears to reconcile the conflicting results of previous experiments. For example, several investigators failed to find a right-ear effect for vowels because they employed stimuli lacking in encoded attributes, i.e., steady-state vowels (Darwin, 1969a; Kirstein & Shankweiler, 1969; Shankweiler & Studdert-

Kennedy, 1967). And although some investigators used stimuli which might have otherwise shown a right-ear advantage, they either utilized a task clearly making the encoded attributes irrelevant (Darwin, 1971; Spellacy & Blumstein, 1970) or employed a procedure that may very well have resulted in uncertainty on the part of the subjects as to the linguistic nature of the task involved (Studdert-Kennedy & Shankweiler, 1970). Where both the appropriate stimuli and a linguistic task are provided, vowels appear to show a distinct right-ear advantage (Darwin, 1971; Haggard, 1971; Spellacy & Blumstein, 1970).

Thus investigations into the right-ear advantage phenomenon have produced evidence to suggest the presence of a linguistic mechanism in the left hemisphere that is involved in some way in the perception of encoded stimulus attributes characteristic of speech. The findings have also suggested, however, that the mere presence of these attributes in the stimulus input is not sufficient to produce a right-ear effect. An additional requirement is a "language set" that makes the encoded stimulus attribute relevant to the identification of the stimulus input.

The studies discussed above have almost exclusively dealt with the nature and the conditions necessary to produce a right-ear advantage. Although much understanding concerning the nature of cerebral dominance with regard to language has been gained, almost nothing is known concerning the nature of cerebral dominance with nonverbal stimuli. As was mentioned above, Kimura (1967) proposed that greater left-ear scores for certain nonverbal functions reflected right-hemispheric specialization for nonverbal functions. Perhaps the most plausible hypothesis would be that there is some kind of perceptual mechanism in the right hemisphere that is specialized for particular stimulus properties characteristic of certain nonverbal sounds, similar in principle to the linguistic mechanism for encoded attributes typical of speech, found in the left hemisphere. Too few experiments exploring the left-ear advantage phenomenon have been conducted to enable an evaluation of such a hypothesis.

An alternative hypothesis has been proposed by Spellacy & Blumstein (1970). It was noted that although a right-ear advantage for vowels was obtained in the language-expectation group, and a left-ear advantage in the nonlanguage group, the aetual recognition scores for the left ear remained the same in the two conditions. Both ear differences resulted almost solely from fluctuation in right-ear performance which is presumably due to left cerebral hemispheric function. The suggestion was offered that when the formant transitions of the vowels were attended to, the result was enhanced perception. However, when the formant transitions were not attended to, perception was decreased. That is, the result of the linguistic mechanism is enhanced perception when these encoded attributes are attended to, and a decrement in perception when these encoded attributes are not attended to. They speculate that "the left ear superiority which was been shown for other nonverbal sounds is due not to increased perception associated with specialized right hemisphere auditory processing, but rather to a decrease of right ear perception due to the inhibiting effects of the right ear signal passing through a speech sound analysis to which S does not attend." (p. 438)

The primary purpose of the present investigation was to explore this possibility. One approach would be to devise a task in which, by manipulating the attentional strategy of the subjects, both right-and left-ear superiorities could be obtained for nonverbal sounds. A simple investigation would demonstrate whether only right-ear recognition was being affected or both. As nonverbal sounds do not possess the necessary encoded attributes required to produce a right-ear effect, such a procedure can not be utilized.

An alternative approach is to use a developmental paradigm. A development of ear asymmetries, reflecting developing cerebral lateralization for the perception of sounds, might be expected with increasing age. Unfortunately, little is known concerning the ages at which ear asymmetries first appear. Two studies by Kimura (1963, 1967) and one by Kimura & Knox (1970) have found that both boys and girls already show a right-ear effect for verbal material at the age of five, although in one study (Kimura, 1967) the right-ear advantage for five-year old boys did not reach significance. The study by Kimura & Knox (1970) also showed a left-ear advantage for environmental sounds present at this age. There are several difficulties with these studies however. Although the procedure used was a free recall paradigm, or a simple modification of it involving the labelling of environmental sounds, order of report factors were not controlled for. A study by Inglis and Sykes (1967) indicates that in free recall procedures order of report factors may have a greater influence upon the dichotic listening performance of children than upon that of adults. That order of report factors may have contaminated the results of Kimura is further suggested by the fact that the degree of ear asymmetry in the experiments decreased rather than increased with age as would be expected if ear asymmetry were reflecting the development of cerebral lateralization for language. A further difficulty is that these results seem to be at variance with neurological studies which used brain-damaged children as subjects. Such studies have demonstrated that through 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, the adult pattern of lateral dominance being clearly established by age 12 or 13 (Lenneberg, 1966; Zangwill, 1960).

A study by Bryden (1970) investigating dichotic listening performance with elementary school children in grades 2, 4, and 6 produced results more in keeping with the studies of brain-damaged children. A dichotic digits free recall task was used but the results were reported in terms of the relative incidence of, rather than magnitude of right-ear superiority. Although the difference in scoring procedure makes comparisons difficult, there is some indication that the frequency of right-ear superiority increases with age in right-handed subjects, and that the adult pattern emerges earlier in girls than in boys. These conclusions are highly tentative, however, and it was hoped that the present investigation would provide further information as to the development of ear asymmetries in children.

The primary purpose of the present study then, was to investigate the nature of ear-asymmetry development, especially in regard to stimulus material showing left-ear superiority. A secondary purpose was to provide confirmation for the premise that left-ear superiority for vowel-varied stimuli is possible under conditions making the encoded attributes a component of a task which elicits a nonlanguage set. And, as mentioned above, an additional aim was to provide clarification as to the influence of age and sex factors on ear asymmetry.

With the above purposes in mind, the present experiment was planned as to procedure, subjects and stimulus material used. To avoid the exaggerating effect of order of recall factors on ear asymmetry, a simple recognition paradigm was decided upon. And on the basis of the studies of brain-damaged children as well as Bryden's (1970) dichotic listening study, elementary school children were chosen as subjects. In an attempt to produce a nonlanguage attentional set, the consonant-varied and vowel-varied stimuli were presented along with music and sound effects.

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, music, and sound effects. Although presumably a nonlanguage set would be created, 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. In contrast, a left-ear advantage for vowels was predicted as the nonlanguage attentional set would presumably change the relevant identification cues from the encoded attributes to the steady-state stimulus properties which vowels have in common with other nonverbal sounds that have produced left-ear effects.

The basis for the predicted left-ear superiority of sound effects, music and vowels in a nonlanguage context, was an assumed decrease in right-ear perception due to the right-ear signal passing through a speech sound analysis to which the subjects were not attending. This hypothesis is in contrast to Kimura's argument that left-ear superiority is a result of increased perception associated with specialized right hemisphere auditory processing. Thus, in the present experiment, it was hypothesized that any increase in ear asymmetry with left-ear advantage stimulus material would be due to a decrease in right-ear recognition, left-ear recognition remaining unchanged. As the right ear effect is presumably due to specialized processing of encoded attributes in the left hemisphere, and as Zangwill (1960) and Lenneberg (1966) have given evidence to suggest that right-hemisphere involvement in language functions decreases as left-hemisphere involvement increases, it was hypothesized that any increase in ear-asymmetry with right-ear advantage stimulus material would be the result of a simultaneous increase in right-ear recognition and decrease in left-ear recognition.

On the basis of Bryden's (1970) developmental study using elementary school children, and the studies using brain-damaged children, as subjects, it was predicted that ear asymmetry would increase with age. Regarding sex factors in ear asymmetry, there is some evidence to suggest that females may show ear-asymmetry with verbal material sooner than males (Bryden, 1970; Kimura, 1967). The differences reported were not significant however, and therefore no predictions were made regarding the effects of sex in the present study.

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 dichotic listening experiments. One prediction was that overall recognition performance would increase with age. This relationship between age and dichotic listening performance has been reported by Bryden (1970), Inglis & Sykes (1967), Kimura (1963, 1967), and Knox & Kimura (1970). It was also expected that subjects would recognize more vowel-varied stimuli than consonant-varied stimuli. This prediction was based on observations by Shankweiler & Studdert-Kennedy (1967, 1970) Kirstein & Shankweiler (1969), and Spellacy & Blumstein (1970).

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

1. A right-ear advantage for consonant-varied stimuli.
2. A left-ear advantage for vowel-varied stimuli, music and sound effects.
3. An increase in ear-asymmetry with age, due to:
    a. an increase in right-ear recognition and a simultaneous decrease in left-ear recognition with right-ear advantage stimulus material.
    b. a decrease in right-ear recognition with left-ear advantage stimulus material.
4. An increase in dichotic listening performance with age.
5. A higher level of recognition performance with vowel-varied stimuli than with consonant-varied stimuli.

CHAPTER III

Method

Subjects

The Ss used were 208 elementary school children in Grades 2, 4 and 6. Four schools were used. All Ss, as judged by their teachers, (a) were right-handed, (b) were in their grade by academic pass, (c) had not repeated a grade, (d) spoke English as their native tongue, and (e) had no known auditory impairment. All Ss were also required, in keeping with the policy of the school district, to have a consent form signed by a parent or guardian. Of the 208 Ss, 19 were excluded because of apparatus difficulty, and 9 because of failure to follow instructions.

Procedure

The apparatus used to present the dichotic stimuli consisted of a Sony TC 630 stereophonic tape-recorder, a six-jack stereophonic listening station, and six sets of stereophonic earphones (Sharpe Pro HA 660). Ss were tested in groups, usually of five, each session taking approximately 30 minutes. Individual desks were placed facing away from the tape-recorder and in a semicircle, to minimize distraction. The tape was presented to the Ss at a low comfortable listening level which was the same for Ss in all conditions. The stimuli were monitored by E through a sixth set of earphones connected to the listening station.

Tape-recorded instructions outlined the nature of the task and provided two examples as well as an opportunity for questions. If there was any doubt as to whether an S understood, instructions were repeated by E in a varied form with additional examples, until there was relative certainty as to S's understanding. This procedure was necessitated most frequently when children in Grade 2 were tested.

The auditory stimulation procedure consisted of 80 dichotic stimulus pairs, 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 followed after four seconds with a diotic recognition foil. There was an interval of five seconds between the recognition stimulus and the onset of the next dichotic presentation. 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 stimulus materials were adapted from a study by Spellacy & Blumstein (1970). Four types of test stimuli were used. Twenty pairs of dichotic stimuli were CVC nonsense syllables that differed in initial consonant. The initial consonants varied were the six stop-consonants

/p, t, k, b, c, g/. Another twenty pairs of dichotic stimuli were CVC nonsense syllables differing in the medial vowel. The vowels varied were /i, e, a, ə, o, u/.

In addition to these CVC nonsense syllables, twenty pairs of dichotic stimuli were exerpts of sung melodies, made up of melodic repetitions of the CVC 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 recording 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 vise versa. A further restriction was that 25 percent of the recognition stimuli were identical with right-ear stimuli, and 25 percent were identical with the left-ear stimuli. The remaining 50 percent were recognition stimuli not used in the dichotic presentation.

Design

A 3x2x4x2 between-within analysis of variance design was utilized, the between factors being grade (G) and sex (S), and the within factors being type of stimulus material presented (M), and ear of presentation (E).

There were three levels of G and four levels of M. Each cell contained 30 Ss.

An increase in dichotic listening performance with age was expected to be revealed in a significant G effect. An analysis of the linear component of this effect was planned to determine the shape of the function. A significant main effect for M was also predicted, and a separate significance test was planned to compare consonant and vowel recognition. A significant MxE interaction was expected, representing a right-ear advantage for consonant-varied stimuli and a left-ear advantage for vowel-varied stimuli, music and sound effects. Separate orthogonal contrasts between ears were planned for the predicted right-ear advantage material and for the predicted left-ear advantage material.

The predicted increase of ear-asymmetry with age would be evidenced by a significant MxGxE interaction, and sex differences in this development would be represented in the MxGxExS interaction. To test the hypothesis that, where increases in ear asymmetry were evident with right-ear advantage stimulus material, this increase would be the result of a simultaneous increase with age in right ear recognition and decrease with age in left-ear recognition, two orthogonal contrasts were planned, one for each ear. The same procedure was planned for left-ear advantage material to test the hypothesis that left-ear superiority is due to a decrease in right-ear recognition with age. As developmental effects are necessarily confounded with grade effects in a developmental paradigm, the grade condition totals for each cell were adjusted to exclude, or at least minimize the exaggerating effects of grade. This analysis was carried out by calculating the average increase across grades for each sex within each stimulus material, and subtracting the average increase from the appropriate condition totals of each ear. (A description and example of the procedure used is included in the Appendix.) With this adjustment to exclude Grade effects, it was predicted that where increases in ear asymmetry were evident, the adjusted data would show an increase in right-ear performance and a simultaneous decrease in left-ear performance for right-ear advantage stimulus material, and a decrease in right-ear performance with no change in left-ear performance for left-ear advantage stimulus material.

CHAPTER IV

Results

A summary of the analysis of variance of recognition scores for the four factors of grade (G), sex (S), ear of presentation (E), and stimulus material presented (M), is presented in Table I. The main effect for G was significant (F=10.73, df=2,174; p <.001). A highly significant portion of the variance attributable to G was due to the linear component (F_{linear}=21.18, df=1,174; p <.001) of the effect, reflecting increased performance as a function of grade level. The mean recognition score for grade 2 was 7.65, for grade 4, was 8.02, and for grade 6 was 8.52. The maximum recognition score possible was 10.

A significant E main effect (F=38.61, df=1,174; p <.001) reflects the fact that in general, more stimuli were recognized when presented to the left ear than when presented to the right ear. The mean recognition score for the left ear was 8.27, and for the right ear was 7.86.

The main effect for M was also significant (F=20.46, df=3,522; p <.001). This effect is illustrated in Fig 1. Consonant identification proved to be the most difficult task with a mean recognition score of 7.51. Music and sound effect stimuli were apparently much easier to identify, with mean recognition scores of 8.34 and 8.39 respectively. Vowels represented a task of intermediate difficulty with a mean recognition score of 8.00. The difference between recognition performance with consonant-varied stimuli and vowel-varied stimuli was found to be significant (F=15.05, df=1,522) at the .001 level of probability. The main effect for S was not significant, nor were any interactions with S.

A significant MxG interaction (F=2.11, df=6,522; p <.05) reflects the fact that the rate of increase in stimulus recognition as a function

Table I

Summary of Analysis of Variance of Recognition Scores

Source	SS	df	MS	F	p
G (grade)	188.03	2	94.02	10.73	$<.001$
S (sex)	13.03	1	13.03	1.49	
GxS	42.37	2	21.18	2.42	
Error (b)	1523.44	174	8.76		
M (material)	174.93	3	58.31	20.46	$<.001$
MxG	35.97	6	6.00	2.11	$<.05$
MxS	0.77	3	0.26	0.09	
MxGxS	9.32	6	1.55	0.54	
Error (w_1)	1486.38	522	2.85		
E (ear)	54.05	1	54.05	38.61	$<.001$
ExG	4.69	2	2.34	1.67	
ExS	1.06	1	1.06	0.76	
ExGxS	6.10	2	3.05	2.18	
Error (w_2)	244.22	174	1.40		
MxE	189.79	3	63.26	50.61	$<.001$
MxExG	17.20	6	2.87	2.30	$<.05$
MxExS	6.32	3	2.11	1.69	
MxExGxS	3.54	6	0.59	0.47	
Error (w_3)	654.53	522	1.25		
Total	4655.74	1439			

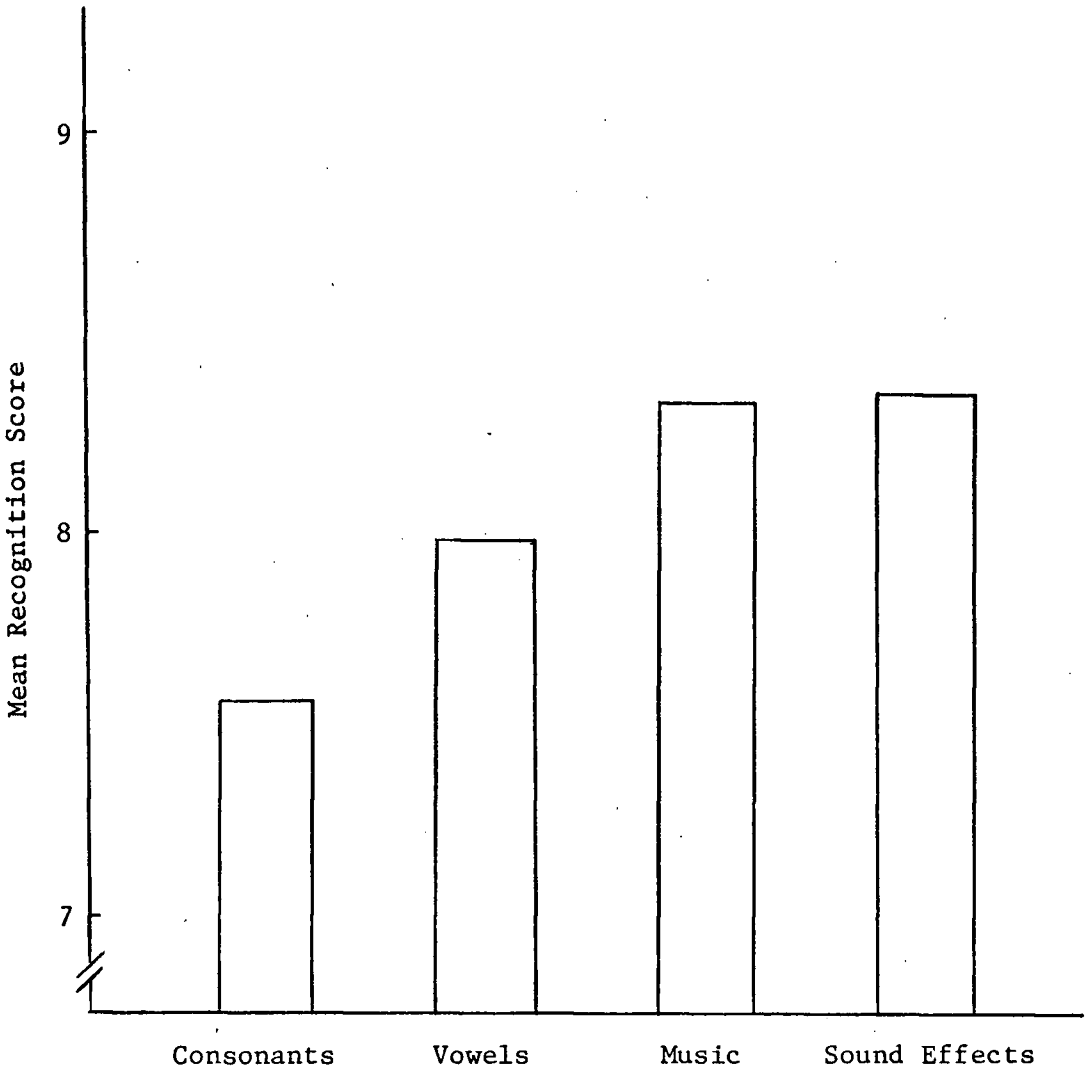

Fig. 1. Recognition performance as a function of the stimulus material presented

of age varies with the stimulus material presented. This interaction is illustrated in Fig. 2. Between grades 2 and 4, the rates of increase in stimulus recognition do not vary greatly with the type of material presented. Between grades 4 and 6, however, a large increase in stimulus recognition is evident for sound effects, a smaller increase for consonants and vowels, and the least increase is evident for music. The mean difference between grades 4 and 6 for sound effects is 1.05 while the mean difference between the same two grades for music is only 0.17. The rate of increase in stimulus recognition remained the same for consonants and music across grades, while vowel and sound effect recognition increased more between grades 4 and 6 than between grades 2 and 4.

The MxE interaction was highly significant (F=50.61, df=3,522; $p < .001$). This effect is illustrated in Fig. 3. Consonant-varied stimuli were more frequently identified correctly when presented to the right ear than to the left ear (F=46.72, df=1,522; $p < .001$). The percentage ear preference for consonants was 5.36. This measure was calculated by dividing the difference between recognition scores for right and left ears by the sum of the recognition scores for both ears, and multiplying by one hundred. Recognition of vowel-varied stimuli, music, and sound effects showed left-ear preferences of 3.32 percent, 6.90 percent and 4.04 percent respectively. The difference between left versus right ear recognition for these stimuli combined was highly significant (F=399.50, df=1,522, $p < .001$).

The one significant triple interaction, MxExG (F=2.30, df=6.522; $p < .05$) reflects the development of ear differences with age, the direction of the ear differences being determined by the stimulus material being presented. This interaction is illustrated in Fig. 4. Consonants, vowels and sound

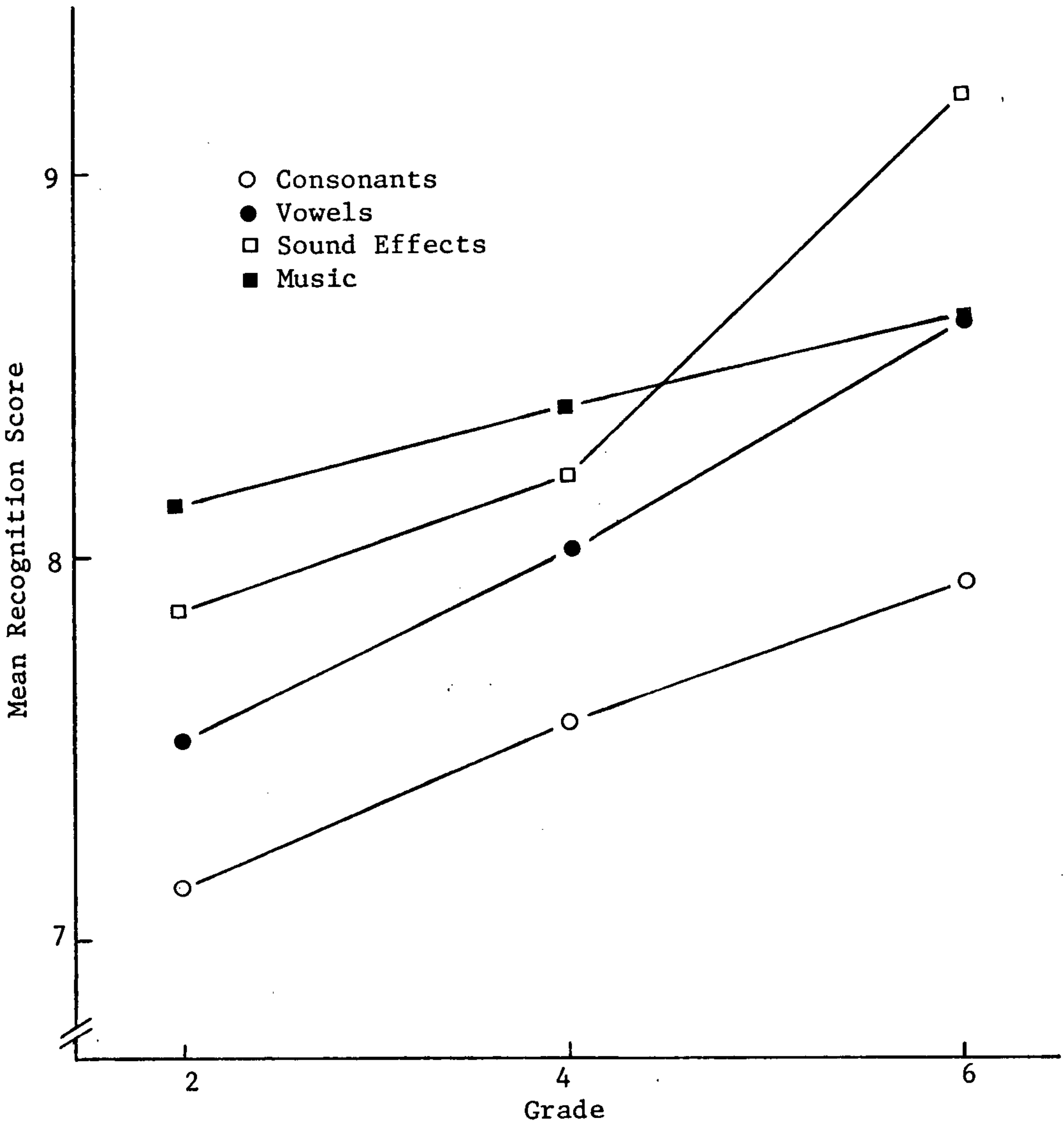

Fig. 2. Increase in recognition of stimulus material as a function of grade

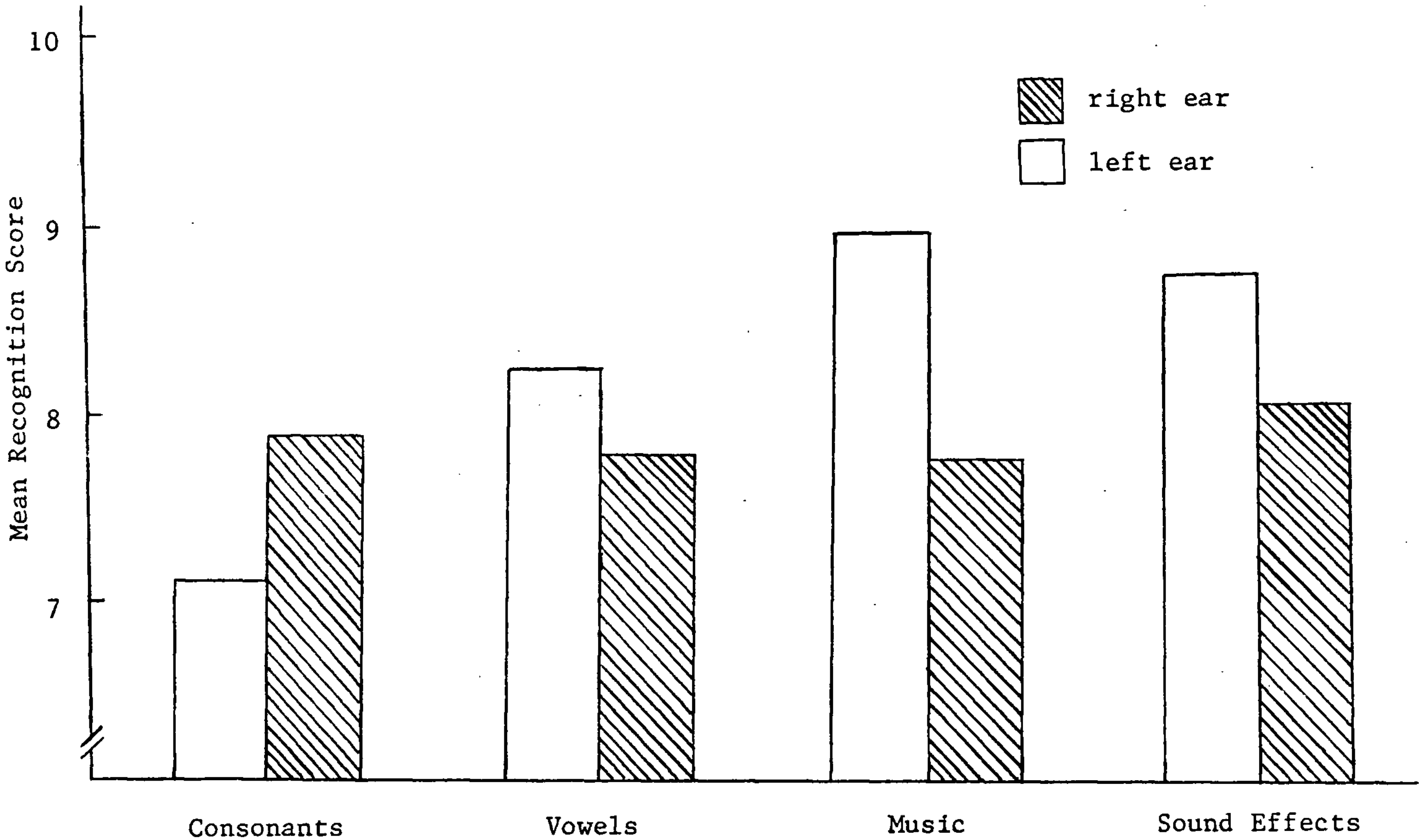

Fig. 3. Ear Preference as a function of stimulus material

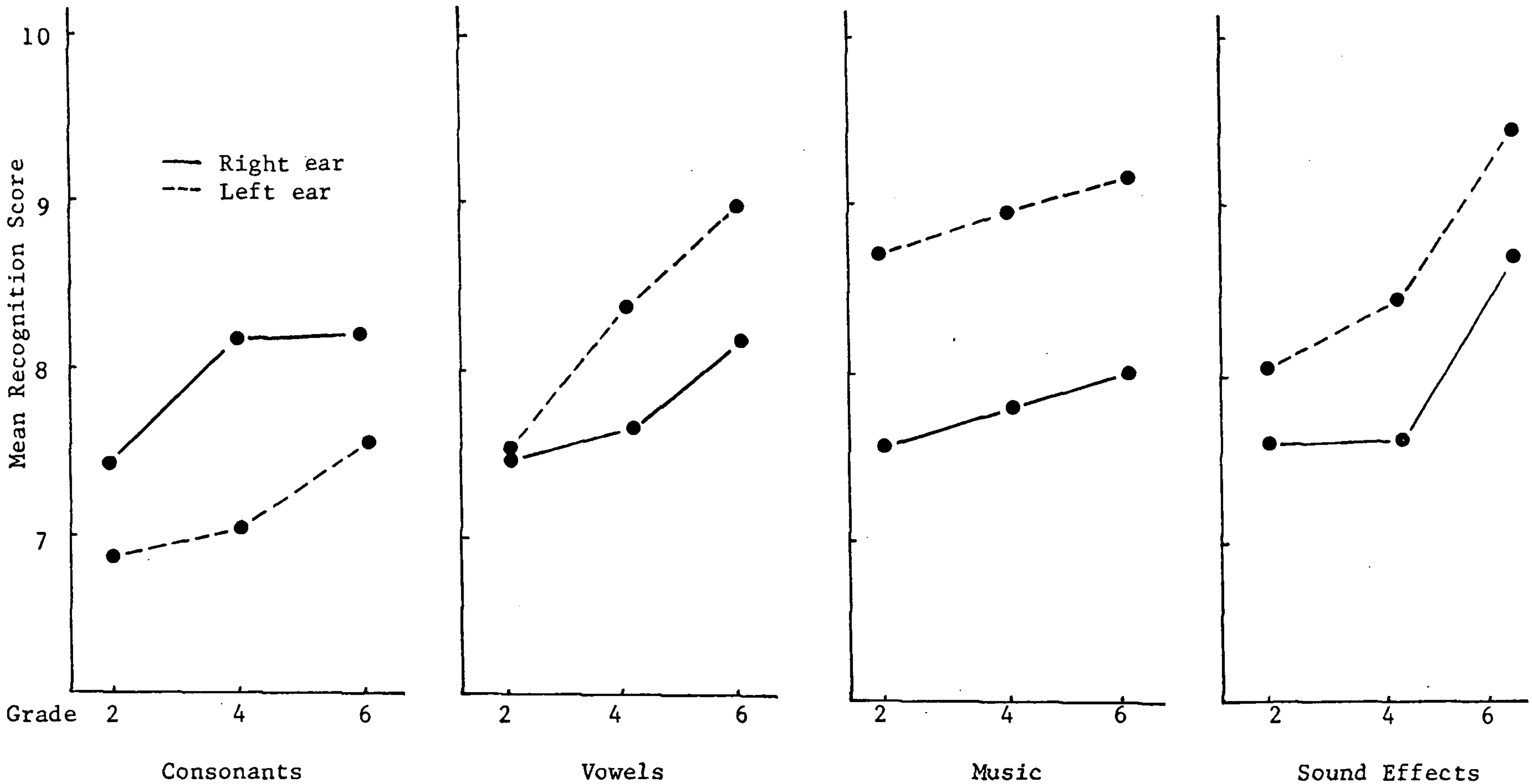

Fig. 4. Recognition scores of stimuli presented to the right and left ears as a function of grade level of stimulus material

effects show increases in ear differences between grades 2 and 4, while music shows no evidence of a developmental trend either between grades 2 and 4 or between grades 4 and 6. Consonants show a decrease in ear asymmetry between grades 4 and 6, while recognition of vowels and sound effects increases at about the same rate for either ear. No ear preference is present for vowels in grade 2, while small ear preferences are present for consonants and sound effects, and a relatively large ear preference is already present for music. Ignoring the direction of the effect, the average ear preference across material is 3.47 percent in grade 2, 5.97 percent in grade 4, and 6.19 percent in grade 6.

Fig. 5 illustrates the development of ear asymmetries from grade 2 to grade 4 separately for each sex. The increase in ear-asymmetry for consonants between grades 2 and 4 illustrated in Fig. 4 is apparently due solely to males, females already showing a 6.12 percent right-ear preference in grade 2, increasing only slightly to 6.50 percent in grade 4. With sound effects, the trend is reversed for males and females, males demonstrating a 6.14 percent left-ear preference in grade 2, while females show absolutely no ear preference and account for almost all of the increase in ear asymmetry from grade 2 to grade 4 shown in Fig. 4. Both sexes show an increase in ear asymmetry in vowel recognition, females showing a faster rate of development than males. Neither sex shows ear-asymmetry for vowels in grade 2. In the recognition of music stimuli, both sexes show a substantial left-ear preference in grade 2 with no sign of further development.

Thus, four developmental trends in ear asymmetry are evident, males showing a developmental effect for consonants and vowels, and females for

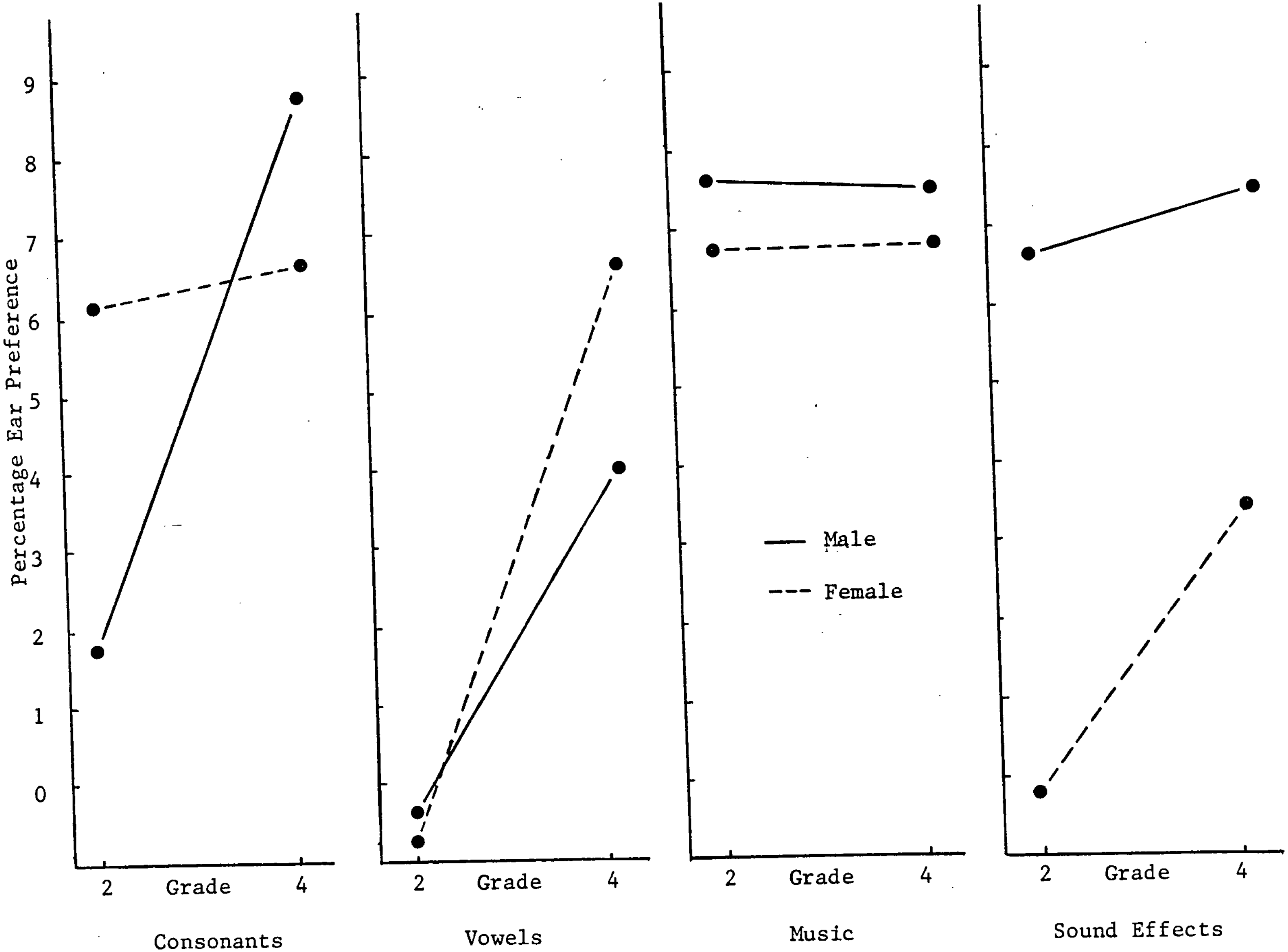

Fig. 5. Sex differences in the development of ear preferences

vowels and sound effects. These trends are illustrated separately for right-ear advantage stimuli and left-ear advantage stimuli in Fig. 6. With grade effects included, a large increase in right-ear recognition ($\underline{F}$=22.43, $\underline{df}$=1,522; $\underline{p} < .001$) with negligible change in left-ear recognition is observed for consonant-varied stimuli. With left-ear advantage stimuli, the reverse trend is observed, recognition of these stimuli increasing significantly ($\underline{F}$=19.95, $\underline{df}$=1,522; $\underline{p} < .001$) for the left ear with only a slight change in the right ear. With grade effects excluded by the method outlined earlier, recognition of consonants presented to the right-ear increases while recognition of the same stimuli to the left ear decreases. For the left-ear advantage stimuli, recognition of the stimuli presented to the right ear decreases while negligible change is evident in left-ear recognition. A summary of this analysis for grade effects included and for grade effects excluded is presented in Tables II and III respectively.

A summary of the analyses of ear asymmetries made by computing separate analyses of variance for each cell is presented in Table IV. With consonants, significant ear differences were found for females in all grades and for males in grades 4 and 6 only. With vowels, significant ear preferences were found for females in grades 4 and 6 and males in grade 6. Significant ear preferences were shown for both sexes in all grades with musical stimuli. With sound effects, although boys showed a significant ear preference across all grades, this preference was evident only in grade 6 with girls.

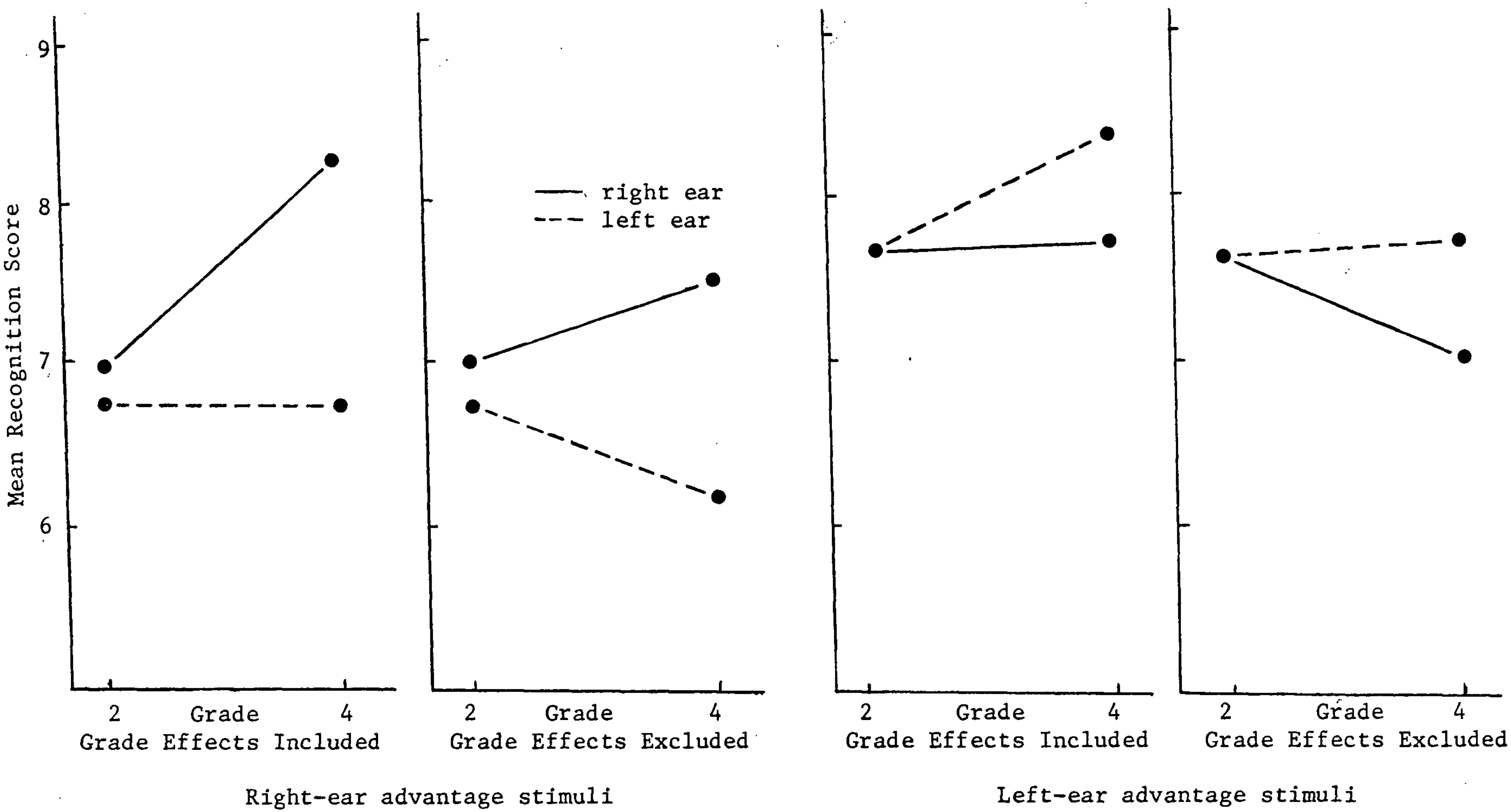

Fig. 6. Nature of the development of ear asymmetries with grade effects included and with grade effects excluded for both right-ear advantage stimuli and left-ear advantage stimuli

Table II

Total Recognition Scores with Grade Effects Included

Sex	Material	Ear	Grade 2	Grade 4	F	p
Male	consonants	left	204	203	0.13	>.90
		right	212	248	22.43	<.001
	vowels	left	219	237*		
		right	217	221**	*19.95	<.001
Females	vowels	left	228	265*		
		right	232	238**	** 0.44	>.85
	sound effects	left	243	255*		
		right	243	240**		

Table III

Total Recognition Scores with Grade Effects Excluded

Sex	Material	Ear	Grade 2	Grade 4
Male	consonants	left	204.0	188.5
		right	212.0	225.5
	vowels	left	219.0	213.7
		right	217.0	197.7
Females	vowels	left	228.0	247.0
		right	232.0	220.0
	sound effects	left	243.0	241.2
		right	243.0	226.2

Table IV

Summary of Separate Analyses of Ear Differences

within Levels of Material, Grade, and Sex

Material	Grade	Sex	Left Ear	Right Ear	F	p
Consonants	2	M	204	212	0.50	>.50
		F	207	234	8.55	<.01
	4	M	203	241	25.06	<.001
		F	216	246	16.12	<.001
	6	M	229	248	5.72	<.05
		F	221	244	13.14	<.001
Vowels	2	M	219	217	0.03	>.90
		F	228	232	0.16	>.35
	4	M	237	221	1.70	>.15
		F	265	238	13.97	<.001
	6	M	275	254	9.30	<.01
		F	264	231	13.35	<.001
Music	2	M	251	216	10.10	<.01
		F	269	236	19.98	<.001
	4	M	265	229	13.25	<.001
		F	271	238	15.78	<.001
	6	M	273	243	8.38	<.01
		F	275	235	23.19	<.001
Sound Effects	2	M	243	215	9.97	<.01
		F	243	243	0	1.0
	4	M	258	223	29.58	<.001
		F	255	240	2.80	>.25
	6	M	290	269	13.13	<.01
		F	282	259	14.44	<.001

CHAPTER FIVE

Discussion

Direction and Nature of the Ear Asymmetries Obtained

The finding of a right-ear superiority with consonant-varied nonsense syllables is consistent with the results of previous dichotic listening experiments using speech stimuli. The explanation that seems most consistent with this finding as well as with previous findings is that there is present in the left hemisphere a linguistic mechanism for processing encoded acoustical cues. A right-ear rather than a left-ear advantage is presumably obtained because of the greater efficiency of the contralateral auditory pathway over the ipsilateral pathway.

The present data show that this right-ear preference for consonant-varied stimuli originally develops from an increment in right-ear performance and simultaneous decrement in left-ear performance with age. These effects presumably reflect the developing lateralization of speech perception in the left hemisphere. As such, the data are in agreement with the evidence obtained from brain-damaged children, these observations showing that through the elementary school years the likelihood of right-hemisphere damage producing long-lasting aphasic disorders gradually decreases whereas the likelihood of left-hemisphere damage producing these disorders increases. The parallel development of a right-ear preference for verbal material and left-hemisphere involvement in the processing of language adds strong support to Kimura's hypothesis of a close relationship between the two phenomena.

The finding of a left-ear superiority for vowel-varied stimuli is relatively unique, having been found previously only by Spellacy &

Blumstein (1970). Although vowels, as do consonants, contain encoded acoustical cues, no right-ear advantage was hypothesized as the nonlanguage set given Ss presumably would result in these cues being made irrelevant to the identification of the stimuli. Thus, the lack of a right-ear preference with these vowel-varied stimuli supports the hypothesis that the mere presence of encoded cues is not a sufficient condition to produce a right-ear effect. The finding thus further emphasizes the importance of task variables in influencing the direction of the ear difference obtained when both encoded and steady-state cues are present.

The left-ear preferences found for music and sound effects are consistent with the data from the relevant investigations discussed above. As to the nature of the left-ear advantage with music, sound effects and vowel-varied stimuli, the data show that this advantage is due primarily to a decrement in right-ear performance, left-ear performance remaining unchanged. This finding presents a challenge to the common practice in neuropsychology of interpreting ear superiority in dichotic listening tasks as a reflection of a perceptual or processing dominance of the cerebral hemisphere contralateral to the ear showing superior performance. According to this interpretation, greater left-ear scores for music and sound effects reflect right hemisphere specialization in the processing of these stimuli. The left-ear advantage with vowel-varied stimuli would probably be explained by Kimura's perceptual bilateral dominance hypothesis by assuming superior perception in the right cerebral hemisphere of the steady-state "music-like" properties of vowels. The present data, however, do not support such interpretations, the left-ear advantage being the result of a decrement in right-ear performance rather than an increment in left-ear performance.

An alternative to the bilateral dominance explanation would be to interpret the data solely in terms of a left-hemisphere specialization for the processing of encoded acoustical cues. It is proposed that such a linguistic mechanism would result in enhanced perception of stimuli when the encoded acoustical cues are attended to, and a decrement in the perception of stimuli when these cues are not attended to. Thus the right-ear decrement would be the result of a right-ear signal passing through a linguistic mechanism to which S is not attending. As there is no decrement in perception of the left ear signal, an apparent left-ear advantage would be obtained. Such an interpretation is more consistent with the present findings.

The unilateral dominance model would also seem to be more compatible with our knowledge of the principles governing evolution. Study of the evolution of the vocal tract in relation to the physiological requirements for producing the sounds of speech suggests that man has evolved special structures for speech-production and has not simply appropriated existing structures designed for eating and breathing (Lieberman, 1968). One would reasonably suppose that man has also evolved matching mechanisms for speech perception. Evidence has already been discussed above which shows that speech perception entails peculiar processes, distinct from those of nonspeech auditory perception. That a specialized perceptual mechanism for speech would therefore be necessary seems fairly obvious. No pressing evolutionary reason, however, is readily apparent for a complementary specialized perceptual mechanism for nonspeech sounds. As the evidence is fairly well documented in regard to a specialized speech mechanism in the left-hemisphere, it would seem more appropriate to consider the effects or resulting cost of such specialization on the auditory processing of nonverbal stimuli rather than to postulate a separate dominance for these stimuli. Certainly such an approach would be more parsimonious given our present state of knowledge. Study of evolutionary history demonstrates that when specialization takes place, it does so at the expense of more expendable functions. It would seem reasonable to expect then, that auditory specialization for speech perception in man would probably interfere with the more expendable perception of nonspeech sounds. As this specialization for speech perception has taken place in the left hemisphere, it would be reasonable to expect that the interference with nonspeech perception would be evident in the same hemisphere. As no specialization for speech perception and therefore no interference with nonspeech perception is evident in the right hemisphere, an apparent left-ear advantage would result.

The postulation of a specialized mechanism for speech perception would thus appear to be all that is necessary to account for both right-and left-ear preferences. Such an interpretation is not only more parsimonious, but is more consistent with evolutionary history, and definitely more compatible with the present data. More enlightened speculation as to the exact nature of the effects of this linguistic mechanism must await further investigation into the nature of variables affecting ear asymmetry.

Developmental Trends in Dichotic Listening

Two major developmental trends are evident in the present results, one being increased performance with age, and the other, increased ear asymmetry with age. Each trend will be discussed separately.

The increase in overall recognition performance with age is reflected in the significant linear component of the grade effect. The phenomenon has been observed by several investigators (Bryden, 1970; Inglis & Sykes, 1967; Kimura, 1963, 1967; Knox & Kimura, 1970) but only Inglis & Sykes (1967) have offered an explanation. They have suggested that increase in performance could be due to an increase in short-term memory storage capacity with age. Although the hypothesis would admittedly be relevant to the multiple-pair-per-trial free recall procedure, it would hardly seem probable that it could account for the linear effect observed in the present experiment where only one pair of stimuli per trial was presented, and where a recognition rather than a recall task was employed. Knowledge of the exact mechanism accounting for this developmental trend will have to await further investigation.

One of the unexpected findings in the present study was the differential effect of age on the recognition of various types of stimulus material, recognition of some materials increasing at a faster rate than recognition of others. The various types of stimulus material also differed in level of difficulty, vowel recognition proving to be easier than consonant recognition, with the recognition of music and sound effects being easier than both. Although a relationship could conceivably be expected between the effect of age on a task and its level of difficulty, comparison of the effects of age on sound effect recognition and music recognition-two tasks of comparable difficulty-negates such a premise. Music recognition is the least affected by age of the stimuli presented, while sound effect recognition is affected the most. Thus the differential effects of age on separate identification tasks remain unexplained.

Regarding the development of ear asymmetry, the present data indicate that in general, the largest portion of the developmental trend takes place before grade 4, only a small increase in ear asymmetry being evident between grades 4 and 6. The actual age at which ear asymmetry is first apparent is somewhat uncertain. Ear preferences are already present in grade 2 for girls in the recognition of consonant-varied stimuli, for boys in the recognition of sound effects, and for both sexes in the recognition of musical stimuli. For the remaining groups, however, no ear-preference is evident in grade 2. For these groups, ear asymmetry is first evident, although not necessarily significant in all cases, in grade 4. Both sexes show significant ear differences in the recognition of all four stimulus materials by grade 6. Although the evidence is not complete, it would seem probable that ear asymmetry first originates between the approximate ages of 5 and 8. The data also show that in general, this asymmetry increases with age through the elementary school years. The data are consistent with the results of studies using brain-damaged Ss, these results showing little difference in the effects of left-versus right-hemisphere damage before the age of 5, and as discussed above, a gradual increase in left hemisphere involvement in language function during the elementary school years. The data are also in agreement with those of Bryden (1970) who has reported an increase in the frequency of right-ear superiority with verbal stimuli from grade 2 to grade 6. However, the present findings contradict those of Kimura (1963, 1967, 1970) who has shown ear asymmetry to be present already at the age of 4, and to decrease rather than to increase with age. An attempt to explain this discrepancy is presented below.

A rather unexpected finding of the present study was the presence of sex differences in ear-asymmetry development. For both consonant-varied and vowel-varied stimulus recognition, boys lagged behind girls, the adult pattern being reached by grade 4 with girls and by grade 6 with boys. Terman & Tyler (1954) present evidence to show that girls excel boys in almost all speaking skills at least in the early school years. If there is indeed a relationship between the earlier development of ear asymmetry with speech stimuli in girls, and their superior ability with language, the present investigation would suggest that this difference may be primarily a developmental one, girls going through the developmental cycle more rapidly than boys, but both arriving eventually at the same level. The basis for this statement would be that while sex differences are found in grades 2 and 4 with verbal material, no such differences are evident in grade 6.

The reverse finding in regard to sex differences is found with sound effect recognition, boys showing ear asymmetry in grade 2 while girls do not do so until grade 6. There is evidence to suggest that boys are superior to girls in visiospatial ability (Terman & Tyler, 1954), but what relation, if any, this ability would have to the recognition of sound effects is not at all clear.

The present study has provided information as to the developmental aspects of ear asymmetry from grades 2 to 6, but does not in itself provide information as to the relation between ear asymmetry at grade 6 and ear asymmetry at maturity. According to the findings with brain-damaged Ss, the adult pattern of cerebral dominance for speech perception is achieved at about grade 6, the effects of brain damage on speech perception remaining relatively constant from this age on. Such observations suggest that little change in ear asymmetry would be evident between grade 6 and adulthood.

To evaluate this premise, the consonant and vowel recognition data from the present experiment were compared with the relevant data from the study conducted by Spellacy & Blumstein (1970) with college students as Ss. When such a comparison is made, the mean recognition scores for the preferred ear are found to be almost the same for Ss in grade 6 and Ss in college. The mean recognition scores for the nonpreferred ear, however, are much lower for the grade 6 Ss than for the college student Ss. For consonants, right ear performance is comparable (mean recognition score of 8.20 vs. 8.21) while the performance on the left ear is less for Ss in grade 6 than in college (8.50 vs. 7.97). For vowels, the reverse is found, left-ear performance being similar (8.98 vs. 9.02) while right-ear performance is much less for Ss in grade 6 than in college (8.08 vs. 8.83). Thus, although preferred ear performance has reached asymptote by grade 6, performance with the nonpreferred ear is still increasing with age. The result is a larger ear difference in grade 6 than at college age, ear asymmetry increasing during elementary school years, and then decreasing to maturity.

Unfortunately, there is a scarcity of relevant data available that can be used to help interpret this phenomenon. As the preferred ear is different for the two materials, the mechanism responsible would appear to be unrelated to cerebral dominance. A differential rate of maturation for the two hemispheres would also fail to account for the phenomenon. A third alternative is the possible influence of order of report factors. Using multiple-pair free recall procedures, both Bryden (1970) and Inglis & Sykes (1967) found an increase in performance with age in favor of the second ear reported. As discussed previously, several investigators have found that the preferred ear is usually reported first, the nonpreferred ear being reported second. At first glance, it would seem highly unlikely that order of report factors would be influencing the results in a one-pair-per-trial recognition procedure. A very tentative possibility could be that an order of report factor in the form of covert rehearsal in favor of the preferred ear is taking place, and thus interfering with the retention of the stimulus presented to the nonpreferred ear. Such a decreased level of performance in the nonpreferred ear would lead to an exaggerated ear preference. This interference with the nonpreferred ear performance would be expected to decrease with age, as order of report factors appear to be negligible in the studies discussed above using adults as Ss. The present findings are compatible with such a notion.

Assuming the above premise to be true, one would expect that dichotic listening studies sensitive to order of report factors would find rather large ear differences at comparatively earlier ages with a progressive decrease in ear asymmetry with age. On the other hand, a procedure relatively insensitive to order of report factors would show ear asymmetry developing at a later age, this ear difference increasing rather than decreasing with age during the elementary school years. To the extent that order of report factors were influencing the results, a decrease in ear asymmetry would be evident between grade 6 and maturity. In view of these predictions, it is rather interesting that Kimura (1963, 1967, 1970), using a procedure rather sensitive to order of report factors, found relatively large ear asymmetry present at the age of 4, with ear differences decreasing progressively with age. In contrast, Bakker (1970) in a recent study using a monotic stimulation procedure in which order of report factors would be completely excluded, found a significant increase in ear asymmetry occuring during the elementary school years. The present investigation, which would be relatively insensitive to order of report factors, also shows this increase in ear asymmetry with age.

It is very unclear at the present state of knowledge whether the interference with retention of stimuli presented to the nonpreferred ear is, in fact, caused by covert rehearsal in favor of the preferred ear, thus resulting in greater ear differences being obtained in childhood than adulthood. It would appear, however, that two separate mechanisms are responsible for the ear asymmetries obtained, one related to cerebral dominance for speech, and the other specific to the identification of stimuli presented to the nonpreferred ear, regardless of whether this nonpreferred ear is left or right.

In general, the results of the present investigation support the hypothesis of a relationship between left-hemisphere specialization for speech and ear asymmetry. Both the age of onset of ear asymmetry, and the positive relationship between magnitude of ear asymmetry and age during the elementary school years, would support such a premise. The data, however, do not necessitate the postulation of a right-hemisphere specialization for nonspeech stimuli. Both right-and left-ear advantages were found to be the apparent result of differences in left-hemisphere function only.

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Appendix

Procedure used to adjust ear condition total in grade 4 for the effects of grade

An estimate of the increase from grade 2 to grade 4 due to the effect of grade was calculated separately for each sex within each type of stimulus material. This was done by dividing the difference between the grade 6 condition total and the grade 2 condition total by four. The resulting sum was subtracted from both the left-ear and the right-ear condition totals in grade 4 to provide an estimate of recognition performance when the increase due to the effect of grade was excluded.

The following is an example of the procedure with consonant-varied stimuli presented to males.

Data

Condition totals for: grade 6 = 477

grade 2 = 416

grade 4 left-ear = 203

grade 4 right-ear = 241

Conditions

Adjusted grade 4 left-ear condition total = grade 4 left-ear condition total $-\left(\frac{\text{grade 6 condition total} - \text{grade 2 condition total}}{4}\right)$

$$= 203 - \left(\frac{477-416}{4}\right)$$

$$= 188.5$$

Adjusted grade 4 right-ear condition total = grade 4 right-ear condition total $-\left(\frac{\text{grade 6 condition total} - \text{grade 2 condition total}}{4}\right)$

$$= 241 - \left(\frac{477-416}{4}\right)$$

$$= 225.5$$