AUDITORY PERCEPTUAL AND MEMORY CAPACITIES OF THE LEFT AND RIGHT HEMISPHERES

by

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ABSTRACT

Twenty-four right handed female college students were presented with dichotic verbal sounds and twenty-four right handed female college students were presented with dichotic non-language sounds. Following the dichotic presentation Ss were required to identify from a group of monaural recognition foils those sounds which had been presented dichotically. On half of the trials the Ss were required to recognize first the sound which had been presented to the left ear and then recognize the sound which had been presented to the right ear. On the remaining trials this procedure was reversed. The dependent measure was the number of correctly recognized sounds. Those Ss presented with verbal sounds showed a right ear preference when recognition was required soon after presentation (mean, approximately eleven seconds). This right ear preference was also shown when sounds were identified later (mean, approximately twenty-five seconds) following the preceding recognition of left ear stimuli. These data are interpreted as reflecting dominant perceptual and memory capacity of the left hemisphere as compared to the right hemisphere. Those Ss presented with non-language sounds showed no evidence for either a right or left hemisphere dominance in the perception or retention of these non-language sounds.

Rather it was found that the Ss recognized more sounds to the ear to which sounds were first presented (both left and right) than the ear to which sounds were presented for storage. This experiment does not support a model which predicts a bilateral asymmetry of auditory function. It is concluded that both cerebral hemispheres participate to an equal extent in the perception and memory of these complex non-language sounds and that compared to verbal sounds, these non-language sounds are not as efficiently entered into short term memory.

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To my loving wife Kathleen

and our three precious children:

Shawn, Audrey, and Michael.

For enduring.

Introduction

Dichotic Listening: A General Introduction

Dichotic stimulation refers to the simultaneous presentation of two different sounds to the left and right ears (Licklider, 1951). This is contrasted with diotic and binaural stimulation. Diotic stimulation refers to the presentation of the same stimulus to both ears. With binaural stimulation one stimulus is also presented to both ears. However, unlike diotic stimulation, there may be phase or intensity differences at the two ears. Monotic stimulation on the other hand refers to the presentation of a stimulus to only one ear.

The dichotic listening procedure has been used as a technique for studying attention, verbal learning, auditory memory and, perhaps most extensively, asymmetry of brain function. In this review emphasis will be focused on the latter category. The prime interest of this writer is to explore those studies in which the dichotic listening procedure has been used to develop models of auditory perception and memory of the left and right hemispheres in man. Also included is a discussion of Broadbent's storage model along with some recent criticisms and modifications of that model, Kimura's perceptual model along with a recent modification of that model, auditory asymmetry and handedness, and auditory asymmetry under conditions of monaural stimulation. In the development of the hypotheses which deal with auditory perception and memory of the left and right hemisphere the issue of recognition versus recall will be discussed.

Broadbent's storage model. Broadbent (1954), in an early application of the dichotic listening procedure, noticed that when subjects (*S*s) were presented with a series of spoken digits, three to each ear at a rate of one pair per half second, they tended to respond by reporting all the digits presented to one ear followed by the digits presented to the other ear. This phenomenon has been referred to as the ear order of report (EOR). Broadbent further noticed that when the interval was increased to one second between dichotic pairs the *S* was able to respond in the temporal order of digit presentation, i.e. left ear-right ear-left ear-right ear or vice versa. However, when the digits were presented with rapid alternation between the left and right ears, i.e. not dichotically, the EOR was not noted. Broadbent concluded that the ability to remember dichotically presented information is more difficult than the ability to remember monotically presented information and suggested that this may be due to perceptual confusion rather than to an actual failure of memory. Further research into the EOR phenomenon led Broadbent (1956) to conclude that the loss of efficiency of memory recall with the dichotic listening procedure is not in storage but rather in the reception of information at the two ears. Information enters simultaneously at the left and right ears but is verbally responded to successively. Such a process implied to Broadbent a storage or delay system.

These findings led Broadbent (1958) to formulate a storage deficit model to account for the EOR phenomenon. This model holds that under rapid rates of dichotic presentation, such as two pairs per second, Ss will show an EOR since it appeared to be the most efficient strategy when Ss cannot rapidly alternate attention between the two ears. With slower rates of dichotic presentation, such as one pair per second, the temporal order of report strategy will be employed. In the EOR condition Ss will process all the information presented to one ear. Broadbent called this the p-system. Information presented simultaneously to the other ear is shunted into a short term store by a filter mechanism. Broadbent referred to this store as the s-system which may be conceptualized as short term memory. After all the information in the p-system is processed, the information in the s-system is retrieved for processing. Broadbent argued that the s-system is used anytime the p-system is already full. Because of the rapid decay of short term memory it is common to find more errors in the delayed s-system than in the p-system.

Recent criticisms of Broadbent's model: In contradiction to the data presented by Broadbent (1958), Emmerich, Goldenbaum, Hayden, Hoffman, and Treffets (1965) present data which show that Ss who switched from one channel to another at a rate of two pairs per second did better than Ss who did not switch. Considering these data Emmerich et al. argue that Broadbent's model needs to be modified in order to take into account the S's ability to make use of a relatively permanent memory system when material facilitating meaningful associations was employed as the dichotic stimulus. This study used one syllable words which formed sentences when perceived temporally. However, Bartz, Satz, Fennell, and Lally (1967) have pointed to serious problems within the Emmerich et al. study which included using a male voice on one channel and a female voice on the other channel, telling the Ss that if the female voice of the first dichotic pair was recorded first some of the answers would form sentences, and allowing Ss to write their responses. Bartz et al. argue that any one of these features was capable of biasing the Ss' responses.

Implicit in Broadbent's storage deficit model is the assumption that under rapid rates of dichotic presentation the EOR occurs. Kimura (1961b) has criticized this position and argues that her data suggest that the predicted EOR seldom occurs. Unfortunately, neither Broadbent nor Kimura have reported the EOR frequencies. Satz, Achenbach, Pattishall, and Fennell (1965) attempted to provide an estimate of the frequency of the EOR. Using three pairs of digits they found that EOR effect occurred 76.42% of the time. These data were interpreted as providing considerable support for Broadbent's model and refuting Kimura's position that the EOR seldom occurs. In a second experiment reported in the same paper Satz et al. observed that if task difficulty was increased (e.g. by using four pairs of digits) there was a tendency for the EOR to decrease.

The model developed by Broadbent is a memory model and is offered as an explanation of why errors occur in short term memory. Recent researchers such as Treisman (1960), Treisman and Geffen (1964, 1968), Triesman and Riley (1967), and Deutsch and Deutsch (1963) have offered various modifications of Broadbent's model but these subsequent modifications still leave a memory model which says little about lateral differences. As the primary interest of the present study concerns lateral differences in auditory perception and memory, attention is turned to Kimura's perceptual model.

Kimura's perceptual model. The dichotic listening procedure has perhaps been most extensively used as a technique for studying functional brain asymmetry.

Kimura (1961a) first noted that the recall of digits presented to the ear contralateral to the site of temporal lobectomy was more impaired following removal of the left temporal lobe than following removal of the right temporal lobe. Prior to surgery however, Ss recalled more digits from the right ear than from the left ear regardless of the site of a lesion. In a group of normal Ss Kimura (1961b) also found a right ear preference. Kimura states that for most people the left hemisphere is dominant for speech and that the contralateral ear is superior in speech recognition. Wada and Rasmussen (1960) have demonstrated that by injecting sodium amytal into the internal carotid artery on one side it is possible to temporarily disrupt the functions of that hemisphere. By using what has become referred to as the Wada Test, Kimura (1961b) was able to locate the speech dominant hemisphere and concluded that when speech was represented in the left hemisphere the right ear was preferred and that the left ear is preferred when the right hemisphere was speech dominant. Kimura has argued that her findings are independent of handedness. Kimura further argues that since she was unable to demonstrate any ear asymmetry under conditions of monaural stimulation both the contralateral and ipsilateral pathways from the ear must be very efficient in normal Ss. Therefore she holds that the ear asymmetry will only be observed in brain damaged cases or in a stimulus competition situation such as the one provided by the dichotic listening task.

The model developed by Kimura is a perceptual model. It holds that under conditions of dichotic stimulation there is an enhanced perception for information presented to the ear contralateral to the speech dominant hemisphere which, for most Ss, is the left hemisphere. Kimura's perceptual model is based on perceptual inequalities between the left and right hemispheres with the left hemisphere dominant for speech perception. Inglis (1962) has rejected the perceptual model offered by Kimura and offers an alternative which is consistent with Broadbent's theory. This model emphasizes storage rather than perceptual asymmetry. Inglis (1968) compared order of report to the perceptual asymmetry phenomenon. The Ss were tested with the dichotic listening procedure under three different conditions: free recall, recall order specified before presentation, and recall order specified after presentation. This study employed several age groups and Inglis found that there was a significant decrement in the material recalled second regardless of whether it was originally presented to the left or right ear. Considering these data Inglis argues that even though there is a laterality effect in the dichotic listening situation the order of report is the major source of variation.

The role of the left hemisphere in speech perception is well documented in the literature (Meyer & Yates, 1955; Milner, 1958). Milner, Taylor, and Sperry (1968) examined a group of patients who had undergone complete commissural section. These patients were only able to respond to speech information that reached the dominant left hemisphere. They were unable to identify objects flashed to the left eye or palmed with the left hand and in a dichotic listening presentation of digits there was near complete suppression by the left hemisphere of inputs from the left ear. Under monaural stimulation conditions, however, they were able to respond to left ear inputs suggesting that ipsilateral pathways can be utilized but not under conditions of dichotic stimulation. This provides further support for the notion of speech dominant hemisphere as well as for the importance of contralateral auditory pathways.

Sparks and Geschwind (1968) have presented extensive dichotic listening test information on a patient who had undergone a complete section of the neocortical commissures. Several different types of dichotic verbal stimuli were administered under a wide range of conditions such as attenuation of signal strength to one of the channels and filtering of the signal to one of the channels. Sparks and Geschwind's findings were similar to those of Milner et al. (1968). They found that under all dichotic listening conditions there was almost complete suppression of information presented to the left ear. When Sparks and Geschwind compared the performance of their patient to that of a group of patients who had suffered extensive damage of the right temporal regions, they found that the patient with section of the neocortical commissures was considerably inferior on the dichotic listening tasks. As with the Milner et al. study, this paper supports the role of the contralateral pathways in auditory perception and the notion that the left hemisphere is speech dominant.

The notion of a speech dominant hemisphere implies that there are qualitative differences between the two hemispheres. Geschwind and Levitsky (1968) have shown that there are also quantitative differences. In an examination of 100 human brains they found that in 65% of the cases the planum temporale behind Heschl's gyrus was larger on the left side, on the right side in 22% of the cases, and 24% of the cases the two hemispheres were equal. Geschwind and Levitsky note that this finding is consistent with the finding that the left sylvian fissure is longer than the right. These data are consistent with a model based on perceptual inequalities since Heschl's gyrus contains the primary auditory cortex while the planum temporale contains the auditory association area which constitutes Wernickes area.

Gazzaniga and Hillyard (1971) explored the language and speech capacities of the right hemisphere. Patients who had undergone a complete section of the neocortical commissures served as Ss as it was possible to present material solely to one hemisphere. Verbal material was flashed to the right hemisphere and the Ss were asked to identify or respond in various ways to characteristics of the stimulus. The general finding was that the right hemisphere is capable of recognizing noun objects, but could not comprehend verbs or respond to printed commands. The authors note that in the more complex semantic syntactic sphere there appears to be no ability of the right hemisphere to recognize either the relations between subjects, verb, and object, the future versus the present tense, or the singular versus the plural case. They did note, however, that the right hemisphere has the ability to determine whether an action sequence is properly represented by an affirmative or negative statement. Gazzaniga and Hillyard conclude that while the extent and exact nature of verbal structure processing in the right hemisphere is unknown those capacities which are present are very primitive. In terms of speech production their data suggest that the right hemisphere is not capable of producing speech.

Kimura's (1961a) contention that the contralateral pathways are in some way more efficient than the ipsilateral pathways is well grounded in physiological research with animals. Rosenweig (1951) in his studies with cats noted that the auditory system is arranged in such a manner that each ear has neural projections to both hemispheres. However, more neural units are stimulated by contralateral stimulation. Similarly Hall and Goldstein (1968), also using cats, have demonstrated that the cortical representation of an auditory stimulus (tone bursts, noise bursts, and clicks) presented to only one ear is greater in the contralateral than the ipsilateral hemisphere.

Considering the fact that no detectable differences in duration have been demonstrated in these studies, the asymmetries that have been observed in dichotic listening studies must be due to the greater number of contralateral impulses stimulating the dominant left hemisphere. At some point within the auditory transmission system, it might be speculated that the contralateral and ipsilateral pathways overlap and at this point the more potent contralateral pathways occlude the ipsilateral pathways thus achieving greater cortical representation. To Kimura, occlusion appears to refer to the suppression of one set of afferents by another. Kimura (1967, 1968) argues that this occlusion situation is ideally demonstrated in the dichotic listening task. More specifically Kimura holds that the observed asymmetries in the dichotic listening task are a result of the contralateral pathways from the right ear occluding the ipsilateral pathways from the left ear. This position reaffirms her earlier assertion (Kimura, 1963a) that a competition situation such as provided by the dichotic listening task is essential to demonstrate ear asymmetry.

A recent modification of Kimura's model: Sparks, Goodglass, and Nickel (1970) used real words and digits in a dichotic listening experiment with both left and right brain damaged patients. These authors suggest that the proposed competition from the contralateral right ear and the ipsilateral left ear is sufficient to account for the effects of a left hemisphere lesion. Sparks, et al. note however that Kimura's (1961a, 1961b) explanation could not account for impaired speech perception when the impairment was confined to the right hemisphere. To explain the deficit in speech perception following damage to the right hemisphere they argue that Kimura's perceptual model would have to be expanded to include the non-language hemisphere and the commissural fibers which return information to each temporal lobe from the ipsilateral ear. Basic to this argument are the assumptions that under dichotic listening conditions contralateral inputs completely suppress ipsilateral inputs and that the competition for language perception and report occurs within the dominant left hemisphere. Thus, as distinct from Kimura's explanation, the competition proposed by Sparks et al. is between the contralateral pathways from the right ear which takes the direct route to the left hemisphere and the contralateral pathway from the left ear which takes a direct route to the right hemisphere and must then follow the transcallosal pathway to the left hemisphere.

In the Sparks et al. study both the right and left brain injured patients showed impaired performance on the words and digits presented to the ear contralateral to the site of the lesion. However, patients with lesions in the left hemisphere also showed an impaired performance for material presented to the ear ipsilateral to the site of the lesion but to a lesser extent. Considering these data the authors suggested that the contralateral fibers connect with the primary sensory areas while the callosal fibers connect with the association areas. Consistent with this extension of Kimura's perceptual model, a lesion in the right hemisphere will impair performance from the left ear but the preferred right ear will be unaffected. Similarly a lesion in the left hemisphere will impair the contralateral right ear if the primary sensory area or the association area is affected. However, if the transcallosal pathway is also affected by the lesion then the ipsilateral ear will be affected. Following this model only a left hemisphere lesion can impair both contralateral and ipsilateral inputs in the perception of speech sounds.

In the Sparks and Geschwind (1968) paper discussed above there was a near complete suppression of information presented to the left ear following section of the neocortical commissures. As in the Sparks et al. study, Sparks and Geschwind argue that the contralateral pathways are of primary importance under conditions of dichotic stimulation. Interestingly however, these authors found that with practice and strong instructions to the S to attend to his left ear he was able to recall some of the material presented to the left ear. This suggests that, under certain conditions in the dichotic listening situation, the left temporal lobe may acquire the ability to separate messages arriving via the weaker ipsilateral pathways.

Asymmetry of Brain Function: The Left and Right Hemisphere

In the preceding sections the dichotic listening procedure has been explained as a technique for studying auditory memory and attention and functional brain asymmetry. Two models have been offered: Broadbent's memory model and Kimura's perceptual asymmetry model. In the sections to follow, a closer examination will be provided of the conditions under which this asymmetry has been observed. Discussion will be provided of the stimulus materials used, strategies of Ss in dichotic listening situations, and researchers' interpretations of their findings. In data interpretation, most researchers discuss their findings within the framework of one of the two models described above or in terms of a modification of one of the models. In general, however, it will be concluded that the bulk of the evidence of studies of functional brain asymmetry is best explained by Kimura's perceptual model or a modification of that model.

The left hemisphere. In Kimura's research discussed above (Kimura, 1961a, 1961b, 1963a) all Ss were permitted free recall, i.e. they could recall the dichotically presented digits in any manner they preferred. Since Ss reported more digits presented to the right ear than to the left, Kimura developed her perceptual model which emphasizes the role of the left hemisphere in speech perception and the superiority of the contralateral auditory pathways. In the section which follows studies will be cited in which report strategies were manipulated with various types of verbal stimuli.

Report strategies and stimulus materials: Inglis (1962, 1968) as noted above has rejected Kimura's position and holds that order of report is the primary variable in dichotic listening. Bryden (1963) has confirmed Kimura's finding of a right ear preference for dichotically presented digits and further noted that Ss preferred the EOR with the right ear reported first. It will be recalled from the Satz et al. study (1965) discussed above that Ss employed the EOR 76.42% of the time. Bryden (1963) also attempted to evaluate the effects of order by instructing Ss to report each ear first equally often. Given this manipulation Bryden found that the right ear preference still held. That is, the right ear was preferred regardless of whether it was used as the immediate recall channel or the storage channel. Bryden interpreted these data as reflecting true perceptual differences between the left and right hemisphere specific to verbal material. In a subsequent paper however, Bryden's active support for the perceptual model was questioned (Bryden, 1964). Three experiments were reported and Bryden noted that Ss used the

the task is difficult enough to produce errors on the immediate channel. Bryden rejects the Inglis hypothesis which holds that ear order effects were due to memory rather than perceptual deficits.

In addition to attempting to provide an answer to the question of how often the EOR is employed Satz et al. (1965) were also interested in investigating the effect of delayed recall under instructed order of report and the relationship between degree of asymmetry and amount of stimulus information. The Ss were tested with four sets of dichotic digits and were instructed to report all the digits from one ear followed by all the digits from the second ear. The left and right ears were reported first an equal number of times. In addition to finding a right ear preference Satz et al. noted that when information presented to the right ear was to be stored for later recall there were significantly fewer errors than when information presented to the left ear was to be stored for later recall. When the number of dichotic pairs was increased from four to six, Satz et al. found that the S's tendency to use the EOR decreased but the laterality effect was greatly increased.

In the majority of studies reported thus far the stimulus material has consisted of digits. Dirks (1963) used real words, filtered words as well as digits in both a monaural and dichotic listening test. Under the monaural conditions there were no significant differences between the left and right ears. Under the dichotic listening condition however, the right ear was preferred for all three types of words. Dirks, like Kimura, argues that in order to demonstrate ear asymmetries there must be competition between the contralateral and ipsilateral pathways.

Bartz et al. (1967) presented Ss with digits, two syllable words such as "able" in which one syllable was presented to each ear and by itself did not form a meaningful word and, two syllable words such as "football" in which one syllable was presented to each ear and did constitute a meaningful word. In all three conditions Ss tended to employ the EOR rather than report in temporal sequences even though meaningful associations did exist between the words. As with the previous studies cited the right ear was preferred for all three types of words and Bartz et al. support the perceptual model. These data however are at variance with Bryden's (1964) earlier contention that verbal associations between the stimuli can influence the S's recall strategy.

Borkowski, Spreen and Stutz (1965) found that when dichotic pairs are constructed of words that have been previously rated on an abstractness-concreteness continuum, words that are more concrete are more efficiently recalled by the right ear. Consistent with the studies by Bryden, Satz et al., and Bartz et al. reported above, Borkowski et al. also noted that the right ear is preferred as the storage channel in situations where the Ss are asked to recall from the left channel first.

Curry and Rutherford (1967) compared the effect of using meaningful words, nonsense words and function words (conjunctions and prepositions such as: if, so, and the) in a dichotic listening task administered to the same Ss. Total recall of both ears was superior for the function words with the nonsense words being recalled least efficiently. For all three types of words Ss showed a right ear preference, however, the function words which were recalled most easily produced the smallest amount of ear asymmetry. Gerber and Goldman (1971) used synthetic nonsense speech sounds and compared S's performance under three different recall conditions. The three conditions were: free recall, ordered recall (Ss instructed which ear to report before stimulus presentation) and ordered after recall (Ss instructed which ear to report after stimulus presentation). As with the above studies, the authors reported a right ear preference for all three recall conditions. Gerber and Goldman also confirmed the Borkowski et al., Bartz et al., Satz et al., and Bryden finding that the right ear is preferred to the left when used as the storage channel. The right ear preference for nonsense words has also been confirmed by Shankweiler and Studdert-Kennedy (1967), Kimura (1967), Spellacy and Blumstein (1970a, 1970b), and Studdert-Kennedy and Shankweiler (1970).

Consistent with these findings of a right ear preference for nonsense words is Kimura and Folb's (1968) finding of a right ear preference for backwards speech sounds. These data suggest that such variables as conceptual content, familiarity, and meaningfulness are not of critical importance in eliciting a right ear preference in dichotic listening.

In a recent paper Goodglass and Peck (1972) examined the ear order report in normal and pathological Ss in a dichotic listening study. The pathological groups were Korsakoff alcoholics and non-Korsakoff alcoholics. The stimulus material consisted of nouns rated as to abstractness, association value, and pronounceability. All Ss were required to report the left ear first followed by the right on half of the trials and the right ear first on the remaining half. For all groups the right ear performance was significantly better than the left and as expected the Korsakoff Ss were considerably inferior to normal Ss. The non-Korsakoff alcoholic Ss were slightly better than the Korsakoff Ss. Perhaps the major finding of this study is that for all three groups the right ear was considerably better than the left ear when information presented to the right ear was to be stored. This finding is consistent with previous studies. Goodglass and Peck support Sparks et al. and Sparks and Geschwind's modification of Kimura's perceptual model. This modification, it is recalled, holds that under conditions of dichotic stimulation it is the contralateral pathways from both ears that are employed in the transmission of verbal information to the left hemisphere. The information presented to the right ear travels directly to the left hemisphere while the information presented to the left ear travels to the right hemisphere and must then cross the corpus callosum to the left hemisphere. Applying this reasoning to their data, Goodglass and Peck offer a first explanation for the right ear preference when information presented to the right ear is to be stored. Stimuli presented to the right ear are immediately transmitted to the left hemisphere where they may be coded for storage in a relatively stable form and consequently remain more available for report after the left ear information has been reported. Goodglass and Peck are not clear in discussing what happens when the left ear signal is to be stored, however several possible interpretations may be considered. First, the left ear signal may be stored in the right hemisphere at a level of coding very close to echoic memory and may consequently be subject to rapid decay. It will be recalled from Gazzaniga and Hillyard (1971) that the right hemisphere has limited language skills. A second explanation may be that the extra synaptic activity involved in crossing the corpus callosum results in a degradation of the signal so that it is stored less efficiently in the left hemisphere than are those arriving directly from the right ear. Third, there may be some qualitative differences in coding and storage mechanisms for information arriving in the primary receiving area from the right ear as opposed to information arriving in the association area from the left ear via callosal pathways. As a final explanation it may be that the process of verbalization involved in the S's report in some way differentially impairs signals to be stored by the left as opposed to those stored by the right ear. Bryden (1971) has discussed some of these possibilities in a paper examining the effects of reporting the attended versus the unattended ear first. While Bryden did not discuss differences between the left and right ears he did note that manipulation of report had a more decremental effect on the attended ear than on the unattended ear.

Goodglass and Peck offer a second possible explanation for the finding that the right ear was preferred to the left when information presented to the right must be stored. They suggest that pre-instructing Ss to report one side first results in different attention levels in the two ears, with a heightening of attention to the ear of first report. If this were the case then the observed lateral disparity might reflect a differential ability to register information when the right as opposed to the left ear is relatively unattended as opposed to a differential memory loss. As a test for this possibility Goodglass and Peck suggest that Ss be instructed which ear to report first after presentation of the dichotic pair. It will be recalled from the Gerber and Goldman study however, that an order after condition was included as well as an order before condition. In that study no significant differences were found between the two report conditions. Thus, it would seem that Goodglass and Peck's first interpretation is more tenable.

The development of right ear asymmetry: In an attempt to determine at what age functional brain asymmetry develops Kimura (1963b) tested four and five year old boys and girls with the dichotic listening procedure. At this young age both boys and girls showed a right ear superiority and there were no apparent sex differences. However, in a replication study with culturally disadvantaged children, Kimura (1967) noted that boys lagged behind girls in the development of speech asymmetry. This lag disappeared at an early age. Kimura attributed this finding to the normal developmental lag of boys as compared to girls and concluded that the left hemisphere is dominant for speech at a very early age. Using children ages five, six, seven, and eight in a dichotic listening test with digits, Knox and Kimura (1970) found a right ear preference for all age groups. No sex differences were found. In a second and third experiment using children of the same age groups these authors found that the right ear advantage still held when two non-verbal methods of report were employed. The non-verbal methods included pointing to pictures of the dichotically presented words and placing objects on pictures where both the objects and the pictures constituted the verbal dichotic stimuli. As with their first experiment no sex differences were found nor did it make any difference whether the Ss used their right or left hand to perform the task. A right ear preference in children for speech material has also been demonstrated by Bakker (1967, 1968, 1969, 1970).

Using the same concrete-abstract continuum for real words, as discussed above in the Borkowski et al. study, Jones and Spreen (1967) tested retarded children. As in the Borkowski et al. study, Jones and Spreen found a right ear preference and noted that concrete words were more efficiently recalled by both ears. These authors concluded that ear preference does not vary as a function of mental age or chronological age. Like Kimura and Dirks, they also stressed the necessity of having competition to demonstrate ear asymmetry.

Bryden and Allard (1973) acknowledge that the dichotic listening studies with children indicate that there is some lateralization of verbal function at a very early age. However, these authors argue that it is not clear to what extent the ear differences found in children are as universal as those found in adults. Because the above cited studies have employed free recall, Bryden and Allard suggest that it is difficult to determine whether the ear advantage observed with children reflects perceptual differences or attentional report, or memory biases irrelevant to cerebral speech lateralization. These authors cite some of their own data in which natural speech consonant vowel (CV) syllables differing only in initial stop consonants were presented to boys and girls from ages six to fourteen. In that study girls showed a laterality effect by grade four (approximately age nine to ten) while the boys lagged considerably behind. In contrast to the data presented by Knox and Kimura, and Kimura, Bryden and Allard argue that their data indicate a gradual development of cerebral lateralization approximating the adult state by approximately age fourteen. This position, they suggest, is consistent with Lenneberg's contention that speech is a biological function and, as such, is subject to the maturation of the brain in much the same way as growth and development.

In the studies reported above, a right ear preference has been demonstrated for digits, real words, filtered words, nonsense words, synthetically produced speech sounds, and backwards speech under a wide range of conditions and with very different types of Ss. It seems reasonable to conclude that the right ear preference for these language sounds is a result of the increased efficiency of the contralateral auditory pathways and the well documented role of the left hemisphere in the processing of language material.

The right hemisphere. The preceding section has dealt with the dominant role of the left hemisphere and the right ear in the perception and memory of speech related sounds. In the next section attention is directed towards the role of the right hemisphere in auditory perception and memory.

Milner (1962) noted that following the removal of the right temporal lobe, performance scores on the Timbre and Tonal Memory subtests of the Seashore Measures of Musical Talents were seriously depressed. Kimura (1964) hypothesized that if damage to the left temporal lobe impaired language recall and damage to the right hemisphere impaired tone performance, then normal Ss should demonstrate a left ear preference for melodies under conditions of dichotic stimulation. In a dichotic listening experiment composed of both digits and melodies administered to the same Ss, Kimura (1964) found a right ear preference for digits and a left ear preference for music. Kimura states that differences between the left and right asymmetries appeared to be along a verbal-non-verbal continuum and, among non-verbal sounds, music is effective in eliciting a left ear preference. Kimura (1967) has further argued that even familiar melodic patterns are best recognized by the left ear, therefore familiarity is not a critical feature in this hemispheric specialization. Rather, she suggests that the critical feature along the verbal-non-verbal continuum, which served to distinguish speech from non speech sounds, are related to articulability. The implication from these data is that the observed asymmetry for music depends on some areas of the brain beyond Heschl's gyrus, probably direct projections to the surrounding superior temporal gyrus and the posterior insular gyrus on the same side (Kimura, 1967). Kimura (1964, 1967, 1968) has offered the same evidence for the observed right hemispheric dominance for music as she does for the left hemispheric dominance for speech, namely perceptual inequality; the contralateral auditory pathways from the left ear occlude the ipsilateral pathways to the music dominant hemisphere (which in most Ss is the right hemisphere).

Shankweiler (1966) administered the digits and melodies dichotic listening tapes employed by Kimura (1961b, 1964) to a group of left brain damaged patients and to a group of right brain damaged patients. Shankweiler found that the efficiency with which the patients responded to the dichotic stimuli varied as a function of the side of the lesion and the nature of the stimulus material. The perception of dichotically presented melodies was selectively impaired by right temporal damage while perception of dichotically presented digits was selectively impaired by left temporal damage. However, those with damage to the left temporal lobe showed better melodic recognition through the left ear, like normal control Ss, while those with right temporal damage showed a reversal, by being more efficient with the right ear. On the digits test the left brain injured patients still retained a right ear preference. Considering these data, Shankweiler postulates that the lateral dominance for verbal material may be more stable than the lateral dominance for musical stimuli. Shankweiler further suggests that his data support a hypothesis of a division of function between the two cerebral hemispheres along a verbal-non-verbal continuum.

In a study similar to the Shankweiler paper, Schulhoff and Goodglass (1969) administered a dichotic music, digits and clicks test to normal Ss, right brain injured, and aphasic left brain injured patients. Of primary interest in this study were the laterality effect and the lesion effect. In addition, order of report was controlled for all types of stimulus materials. As expected, normal Ss showed a right ear preference for digits, a left ear preference for tonal patterns, and counted clicks equally well with either ear. The patients with right temporal injury showed a unilateral decrement for digits presented to the left ear and a bilateral decrement for tonal sequences. The left ear preference for the tonal patterns was maintained in the right brain injury group. The left brain injured patients, on the other hand, showed a unilateral right ear decrement for the tonal patterns and a severe bilateral decrement for digits. The normal right ear preference for digits, as found with normal Ss, dropped to a non-significant margin. Furthermore the authors noted that six of their ten left brain injured patients showed a reversal in ear preference. Both the brain injured groups showed an equal impairment in the click counting tasks with the ear contralateral to the lesion significantly inferior to the ipsilateral lesion.

In considering the laterality effect Schulhoff and Goodglass note that it has two manifestations. With normal Ss it takes the form of report preference for information presented to the ear contralateral to the hemisphere dominant for the given material. In brain injured patients the laterality effect manifests itself in a bilateral decrement in performance in material for which the damaged hemisphere is dominant. The lesion effect, on the other hand, manifests itself by a deficit in the ear contralateral to the injured hemisphere regardless of which hemisphere is dominant for the given material. Schulhoff and Goodglass also note that there is an interaction between the lesion and laterality effect. Injury to the right hemisphere tends to widen the margin of preference of the normally superior ear. However, injury to the left hemisphere decreases the margin of preference of the normally preferred ear and frequently reverses the direction of ear preference. Similarly, in a brief review paper on laterality effects in dichotic listening studies, Satz (1968) argues that the right hemisphere is dominant for auditory pattern discrimination.

Components of music and other non-language stimuli: Curry (1967) tested normal Ss with three different dichotic listening tests: meaningful words, nonsense words and environmental sounds (e.g. a car starting or a toilet flushing). Curry suggested that this last task was essentially non-verbal in nature. As expected the right ear was preferred for both the verbal tasks while the left ear was preferred for the environmental sounds. Curry suggested that these data support the notion that there are different neurophysiological mechanisms involved in the processing of auditory stimuli in the two hemispheres.

Bakker (1967, 1968, 1970) in a monaural test used Morse code type sound patterns generated by a buzzer and found a left ear preference for these non-language stimuli. Murphy and Venables (1970) have suggested that the primary role of the right hemisphere is concerned with pitch analysis. Using a signal detection analysis they found a left ear preference for the fusion of two clicks. This left ear preference was accentuated when the opposite ear was presented with a burst of white noise.

Spellacy (1970), using the dichotic listening procedure, attempted to isolate components of music which might contribute to the left ear preference. The dichotic stimuli consisted of music, temporal patterns, frequency patterns, and timbre. The Ss were tested by means of recognition after five seconds or after twelve seconds. While the frequency patterns, temporal patterns, and timbre failed to achieve significance, the music stimuli were highly significant. Of more interest however, was the time interval. Spellacy had hypothesized that if the storage model held, the twelve second interval should reveal more asymmetry. On the other hand, he suggested that if the perceptual model was appropriate, the shorter interval should reveal greater asymmetry. The left ear preference was highly significant at the five second interval but not at the longer interval. Spellacy concluded that the perceptual model which does not imply two different types of memory best fit his data.

Spreen, Spellacy, and Reid (1970) examined the effects of high and low intensity in a dichotic listening test with music and tonal patterns. In addition to the left ear preference for music they noted that recognition scores for musical stimuli were significantly higher than for tonal patterns. These authors confirmed Spellacy's (1970) finding that the size of the difference between the ears for music and tonal patterns decreased with an increase in the length of the time interval. These data were accepted as providing further support for the perceptual model. No significant differences between the two levels of intensity were reported.

Gordon (1970) administered three dichotic listening tests to a group of normal Ss. The three tests included a digits test, a melodies test generated by a recorder, and a chords test generated by an electric organ. The melodies test was a whistle-like tone largely devoid of timbre and chordal variation while the chords test was rich in overtones for timbre quality. Gordon found a right ear non-significant preference for digit recall. On the melodies test there were no differences between the ears with both the left and the right ear performing considerably above chance level. On the chords test however, the left ear was significantly preferred to the right ear with the right ear performing barely at chance level. Considering these data, particularly the failure to observe ear asymmetries on the melodies test, Gordon suggests that the lack of preference is due primarily to the rhythmic aspects of the stimuli rather than to any qualitative pitch differences. Thus, the equal performance of the two ears on the melodies test suggests a bilaterality of rhythmic function. The variations of the melodic line and the complex pattern of pitches produced by the chords, however, resulted in a significant left ear preference. Gordon concludes that while there is bilaterality of function for rhythm, discrimination of the complex pattern demanded by the chords test are those features which are most likely lateralized to the right hemisphere. These data are consistent with those presented above by Spellacy (1970) and

Spreen, Spellacy and Reid (1970) where the left ear preference was found only with musical stimuli.

In a study similar to Gordon's, Spellacy and Blumstein (1970c) presented Ss with speech sounds and two types of non-language sounds: music and sound effects. Unlike previous dichotic listening studies in which non-language stimuli were used, the music and sound effects stimuli used in the Spellacy and Blumstein study were created by a human voice. A significant right ear preference was observed when Ss were presented with the speech sound. However, when Ss were presented with the non-language sounds a left ear preference was observed only for the music and not the sound effects. Of particular interest in this study was the finding that the left ear preference in the music test was not due to an increase in performance of the left ear but to a decrease in performance of the right ear when compared to the speech condition.

Recently King and Kimura (1972) presented Ss with a dichotic listening music test in which a human voice was used as the stimulus source. The different groups of Ss were presented with two different dichotic listening tests. One of the tests employed hummed concert melodic patterns by a young woman, the other test used human emotional sounds such as laughing or crying. On both tests Ss showed a significant left ear preference suggesting to King and Kimura that the right hemisphere is primarily involved in processing these non-verbal stimuli which however were produced by human voices. These data support the interpretations and provide replication for the above cited Spellacy and Blumstein paper. King and Kimura further argue that these data are considered to support a division of function between the two hemispheres along a verbal-non-verbal continuum.

The development of left ear preference: In the Knox and Kimura (1970) study cited above with children ages five to eight, a non-verbal dichotic listening task was also employed. The non-verbal stimuli were the same environmental sounds used in the study cited above by Curry (1967). In the first experiment reported in this paper (Knox & Kimura, 1970) the left ear was preferred to the right for all age and sex groups. Furthermore, boys of all ages had a significantly higher combined left and right ear score than did girls. In the second experiment the reported left ear preference was again noted for all age and sex groups except the five year old girls. No apparent sex differences were noted. When animal sounds were introduced as the dichotic stimuli, the left ear was preferred although not significantly, to the right. Combined scores for the left and right ears showed boys to be significantly superior to girls. When the animal sounds were presented binaurally to Ss ages two-and-one-half to five, male recognition scores were superior to those obtained by females. Considering these data, Knox and Kimura suggest further support is obtained for the division of function of the two hemispheres along a verbal-non-verbal continuum. Furthermore, this lateralization of function tends to be apparent in both boys and girls as early as age five. That boys tended to perform better than girls on the non-verbal tasks is best explained in terms of innate psychological capacities or in a differential maturation of right hemisphere function (Knox & Kimura, 1970).

In the above studies using tones, buzzer produced sounds, environmental sounds, human produced emotional sounds, human produced melodies, and music, a left ear preference has been found. These sounds have been defined as non-language. Following the bilateral perceptual asymmetry model, one could argue that these non-language materials are most efficiently processed in the right hemisphere by most Ss and that the contralateral ear is therefore preferred for recognition or recall. It should be pointed out however that the left ear preference for non-language sounds is less frequently reported than the right ear preference for speech sounds and the effects are generally smaller. Furthermore, many researchers have been unable to demonstrate a left ear preference. Spellacy (1968) used environmental sounds (e.g. fog horn, siren) very similar to those employed in the Curry study cited above and was unable to demonstrate any ear preference. Thus, it would appear that the right hemisphere story is less clear than many writers have suggested.

Asymmetry of function and handedness. Kimura (1961b, 1963a, 1967, 1968), in discussing her brain damaged patients, has noted that right-handed patients showed a language deficit when the lesion was in the left hemisphere while left handed patients tended to show a language deficit when the lesion was in the right hemisphere. She concluded that her findings are independent of handedness. Furthermore, she has argued that the ear contralateral to the language dominant hemisphere is more efficient, independent of handedness.

It must be pointed out however that the independence of handedness can only be demonstrated in those studies in which the actual hemisphere containing speech representation is known (Kimura, 1967) which is frequently possible with brain damaged patients. In normal populations localization of speech representation within the cortex is usually not known, therefore the researcher can only expect handedness to be related to speech dominance to the extent that cerebral dominance for speech is related to handedness. Compared to left handed Ss, normal right handed Ss appear to be a relatively homogeneous population. Using the Wada Test, Branch, Milner and Rasmussen (1964) estimated that 90% of all right handed Ss have speech represented in the left hemisphere. Left handed Ss appear to be much more heterogeneous. Branch et al. estimated that only 60% of left handed Ss have speech represented in the left hemisphere. It is this for this reason that most studies have only used right handed Ss. Many researchers screen their Ss with questionnaires attempting to establish the degree of "right handedness."

Curry and Rutherford (1967) included a group of left handed Ss in their study and noted that there was less asymmetry for the left handed group in processing speech material. They suggested that left handed Ss may have a greater equipotentiality for language function than right handed Ss. A similar observation and interpretation was drawn by Curry (1967) who also included a left handed group of Ss. Satz, Achenbach, Pattishall, and Fennell (1965), using digits as the dichotic stimuli, compared the performance of left and right handed Ss. They found that the degree of asymmetry was greater for right than left handed Ss. Furthermore, they noted that the smaller ear asymmetry was independent of the preferred ear. Satz et al. suggest that this smaller asymmetry in left handed Ss may reflect a lack of a fully developed or dominant speech hemisphere in those Ss.

Satz, Achenbach, and Fennell (1967) compared left and right handed Ss on a dichotic listening test and on three measures of manual performance. The dichotic listening test employed digits as the stimulus material and the measures of manual performance were strength of grip, speed of tapping, and manual dexterity. Self-classified left handed Ss demonstrated variable lateral performance on both the manual and dichotic listening tests. Self-classified right handed Ss were much more reliable and their performance on the manual tests were highly correlated with their superior right ear preference on the dichotic listening test. Satz et al. test classified the fifty-four left handed Ss on the basis of their composite manual performance scores. Three test classified groups were distinguished: strongly right handed, which comprised (17%) of the left handed group; ambidextrous (22%); and strongly left handed (61%). The first two groups demonstrated a right ear preference for speech while the final group demonstrated a left ear preference. Since self-classified left handed Ss were found to vary along levels of manual and speech laterality, the authors concluded that self reports of left handedness were an unreliable estimate of manual dexterity.

Hécean and Sauquet (1970), in studying right and left hemisphere syndromes in left and right handed Ss, noticed that the comparison between left and right hemisphere syndromes in left handed Ss displays less difference between frequencies of symptoms than the same comparison in right handed Ss. While their findings indicated that there appears to be a cerebral ambilaterality in left handed Ss they also indicated, as did Satz et al., that left handed

Ss do not appear as a single group. Further examination of their left handed group suggested that with familial left handedness, reading and language disturbance occurred with comparable frequency following lesions to either hemisphere. With non-familial left handed Ss, however, these disturbances were seldom present with lesions to the right hemisphere. Thus Hécean and Sauquet concluded that the cerebral ambilaterality, as hinted at by Curry and Rutherford, occurs only with familial left handed Ss.

Monaural versus dichotic stimulation. In this section literature which has attempted to show ear asymmetry under conditions of monaural stimulation will be reviewed. While not directly germane to the development of the hypotheses in subsequent sections, it is worthwhile including as it questions a basic assumption in studies of ear asymmetry, namely that competition is necessary in order to show an ear preference.

Both the storage and perceptual models and the modifications of those models discussed above imply that dichotic stimulation is necessary in order to demonstrate an ear asymmetry. Kimura (1963a, 1964, 1967, 1968) holds that competition between the contralateral and ipsilateral pathways is necessary for ear asymmetry to be demonstrated. Kimura (1964) suggested that the dichotic situation places more demands on the perceptual system than the monaural does. Dirks (1964) and Jones and Spreen (1967) have also argued that sounds must be competing in order to demonstrate ear asymmetry. In a recent paper, Bryden (1969) reported a series of experiments. In the first two experiments words were presented monaurally, however the Ss did not know to which ear the words would be presented. In these two experiments no laterality effect was found. In the third study Ss were presented with a list of words which required variable rates of switching time between the two ears. Still no laterality effects were observed. In a final experiment, Ss were tested dichotically and order of report was controlled. Half of the Ss were told before stimulus presentation which ear to report first and the other half were told which ear to report first after stimulus presentations. In both report conditions of the dichotic test a significant right ear preference was found. Bryden concludes that competition between inputs is both a necessary and sufficient condition for an ear preference to be observed. Studdert-Kennedy and Shankweiler (1970) argue that there are two necessary conditions to produce an ear preference in dichotic listening. First, some part of the perceptual process must depend upon unilateral machinery and second, the input from the ipsilateral ear must suffer some form of degradation either as a result of its transmission to the dominant hemisphere or as a result of decay. Whenever a contralateral ear preference is noticed, they argue that these conditions must have been fulfilled.

In the majority of studies cited above, the dichotic stimulation procedure has been used. The emphasis that many researchers have placed on competition is understandable since most attempts with monaural stimulation have failed to produce ear asymmetry. In a few studies however, auditory asymmetry has been observed under conditions of monaural stimulation.

One of the first studies was provided by Simon (1967). The stimulus was a 1000 Hz tone and the dependent measure was key press reaction time (RT). Both left and right handed Ss were used in this study. The stimulus was presented randomly to the left, right, or both ears. Simon found that RT was significantly faster for right ear stimulation than for the left ear stimulation. It was also noted that diotic trials were significantly faster than monaural trials. In a separate experiment reported in the same study, Simon noted that when Ss were told in advance as to which ear would be stimulated, the right ear preference disappeared and the difference between diotic and monaural stimulation was no longer significant. Simon argued that the perceptual model, as developed by Kimura, does not fit his data and adopted an expectancy explanation. This explanation holds that when the S is uncertain as to which ear will be stimulated he "tunes in" his right ear thus yielding faster RTs for right ear stimulation. With diotic trials the expectancy explanation holds that the S would always be listening with one ear or the other hence would always be correct where he would not be correctly listening on some monaural trials. If the uncertainty is removed, through instructions to the S, then the right ear preference and the diotic preference should disappear.

Simon's findings are of particular interest for two reasons. First, auditory asymmetry was demonstrated under conditions of monaural stimulation and second, a right ear preference was demonstrated for stimulus material that should elicit a left ear preference if the original language-non-language continuum as proposed by Kimura is followed.

Bakker (1967) also found ear asymmetries under conditions of monaural stimulation. The stimuli consisted of both verbal material (digit series composed of four, five, or six digits) and non-language material (Morse code sound patterns of dots and dashes generated by a buzzer). The Ss were children ages six to twelve. With the verbal stimuli the Ss were instructed to repeat the digits following series presentation while the non-language material was to be reproduced with the aid of a buzzer. For both classes of stimuli exact temporal order of response was required before a response was considered correct. The non-language material was retained significantly better with the left ear than with the right. The verbal material, while in the hypothesized direction of a right ear preference, did not achieve significance. Bakker suggested that the verbal material was too easy a task whereas the non-language was not. Bakker (1968), using the same procedure as before (Bakker, 1967), tested boys ages nine to thirteen with learning disabilities. The non-language stimuli were retained better when presented to the left ear than when presented to the right ear. The digit series were once again in the hypothesized direction but not significant. Bakker argued that the stimulus competition situation as described by Kimura and others may be one of the factors contributing to asymmetry but that it is not so much the manner of stimulus presentation (i.e. monaural or dichotic) as it is the type of task that is vital in the demonstration of ear asymmetry. As in the previous study, correct order of report was demanded before a response was accepted as correct.

In an attempt to test the notion that it is the type of task as opposed to the manner of stimulus presentation, Bakker (1969) compared three methods of recall with monaural verbal stimulation. The verbal stimuli were series of four and five letters and were presented to ten year old children. The recall methods were: free recall in which the S was required to produce all the letters but in any order; serial recall in which the S was required to produce all the letters in order of presentation and; ordered recall in which a S was told one of the letters of the series after stimulus presentation and was then required to report its exact location within the series. Bakker found that in all conditions the four letter series were retained better than the five letter series. In the serial recall and ordered recall conditions, a right ear preference was observed whereas no ear asymmetry was found in the free recall condition.

Considering the above data, Bakker (1968, 1969) argued that ear asymmetry is dependent on the nature of the task. The requirement of ordered recall and the length of the task are critical variables. Bakker further suggested that another factor contributing to the asymmetry observed in his studies is that the same hemisphere which is involved in verbal processing is also primarily involved in events ordered temporally. Such an explanation would account for material that is both verbal in nature and temporally ordered.

Bakker (1970) tested children ages seven to thirteen with both verbal and non-language stimuli monaurally presented. The verbal material was series of four, five and six digits and the non-language material was buzzer produced series of dots and dashes three, four and five elements long. The medium length series (four) of non-language stimuli produced the greatest amount of left ear preference while the longest length series (six) of the verbal stimuli produced the greatest amount of right ear preference.

Furthermore, it was found that right eyed children showed a right ear preference for verbal material and children with normally developed lateral awareness showed a right ear preference for verbal stimuli and a left ear preference for non-language stimuli.

Bakker (1970) concluded that ear asymmetry under conditions of monaural stimulation appears to be related to the length of the series and the requirement that the stimulus material be temporally ordered. As a further explanation for monaural asymmetry he suggested that information to be processed in the dominant hemisphere (left for verbal and right for non-language) is more efficiently transmitted by the contralateral auditory pathways. When information is presented to the ipsilateral ear, there is a greater number of synapses resulting in a greater loss. The implication from this argument is that even under conditions of monaural stimulation, information presented to the ear ipsilateral to the dominant hemisphere is transmitted via contralateral pathways and must therefore cross the corpus callosum to reach the dominant hemisphere. This position is consistent with the bilateral perceptual model by Sparks and Geschwind (1968) and Sparks et al. (1970) which is discussed above.

The demonstration of a left ear preference for non-language stimuli is interesting considering Bakker's (1969) suggestion that material which must be temporally ordered is most efficiently done in the verbal, left hemisphere. In the present study, Bakker (1970) noted that for verbal stimuli right ear preference was at its maximum under the longer series condition while for buzzer patterns left ear preference was at its maximum at the medium length. Referring to studies of the effects of right temporal lobe damage as discussed above, Bakker suggested that imitation of rhythmic patterns is temporally mediated by the right hemisphere while the verbal stimuli are temporally mediated by the left hemisphere. Bakker concludes by suggesting that series of varying types of auditory stimuli (e.g. digits, tones, etc.) are temporally mediated and the nature of the auditory stimuli determines which hemisphere will be employed.

Murphy and Venables (1970) have also provided evidence for ear asymmetry under conditions of monaural stimulation through the use of a signal detection task. Clicks with a varying interval between them were presented to one ear and the S was required to indicate whether he identified one or two clicks. Murphy and Venables found that left ear performance was superior to right ear performance. When white noise was presented to the ear opposite the clicks, the left ear preference was accentuated. These authors interpreted their data as consistent with Kimura's (1964) and Milner's (1962) and argue that the left ear is preferred for non-language material due to the dominant role of the right hemisphere.

In a recent study, Doehring (1972) attempted to investigate ear asymmetry for frequency and intensity discrimination using monaural tonal sequences. Previous research in which the tones were presented at 80 dB had failed to produce any ear asymmetry and Doehring attributed this to the fact that the high intensity tones could have stimulated the contralateral ear through bone conduction or that the tonal patterns could have produced sufficient stimulation of the ipsilateral pathway to overcome the advantage of the contralateral pathway. In the present study the maximum intensity employed was 60 dB. For intensity discrimination the left ear was significantly preferred to the right ear. For frequency discrimination there was a trend in the direction of a left ear preference but this difference was not significant. Doehring offers these data as further evidence for ear asymmetry under conditions of monaural stimulation.

Haydon and Spellacy (1973) used consonant-vowel-consonant (CVC) speech sounds and a 1000 Hz tone in a monaural test for ear asymmetry. The paradigm employed was very similar to the one reported above in the Simon (1967) study. The stimulus sounds were presented to the left ear only, to the right ear only, or to both ears. The dependent measure was key press RT. The two classes of stimuli were administered on separate days. Half of the _Ss_ were told in advance which ear would be stimulated while the remaining half were not. They found that when Ss were uncertain as to the site of stimulation RTs to right ear stimulation were significantly faster than those obtained for left ear stimulation. This finding was observed for both the CVC sounds and the 1000 Hz tone. The finding of a right ear preference for CVC sounds is consistent with Kimura's notion of a verbal-non-verbal continuum, however the finding of right ear preference for pure tones, as was noted in the Simon study, is contradictory to what might be expected. This issue will be discussed in the next section.

Haydon and Spreen (1974) tested educable retarded adolescents with a dichotic listening test and with the monaural tonal test employed in the Haydon and Spellacy study. With the dichotic listening test, the right ear scores were superior to the left ear scores, however, this difference was not statistically significant. With the monaural tonal test, on the other hand, RTs to right ear stimulation were significantly faster than those to left ear stimulation. Haydon and Spreen suggested that the monaural technique may be a more sensitive estimate of cerebral dominance than the dichotic listening test in a population where memory deficits are already suspect.

Thus it appears that stimulus competition is a sufficient but not necessary condition for eliciting ear asymmetry. In terms of ear asymmetries many of the studies employing monaural stimulation support the dichotic listening studies: namely a right ear preference is found for speech sounds and a left ear preference is found for non-language sounds. The papers presented by Simon, Haydon and Spellacy, and Haydon and Spreen however present a marked exception to the notion of a verbal-non-verbal continuum.

Bilateral hemispheric specialization. From the above discussion of right and left ear superiority, it would appear that the functions of the left and right hemispheres of the brain in auditory perception were known. The left hemisphere is dominant for speech sounds and the right hemisphere is dominant for non-language sounds, speech and non-language being defined in terms of the above findings. Several recent studies, however, have questioned this distinction.

Shankweiler and Studdert-Kennedy (1967) used the dichotic listening procedure to determine whether all features of phonetic elements are processed the same way. They also examined at what stage in the processing of speech hemispheric differences in function became evident. The stimuli employed in this study consisted of synthetically produced consonant-vowel (CV) syllables and synthetically produced steady state vowels in isolation. Shankweiler and Studdert-Kennedy found a significant right ear preference for

CV sounds but not for vowels. The authors concluded that laterality effects occur in dichotic presentation of nonsense syllables displaying phonemic contrasts. This implies that the speech dominance of the left hemisphere is in speech perception at the level of speech sound and structure. Furthermore, these authors argue that since the laterality effect was greater for CV pairs differing on two articulatory features than on pairs differing on one, this implies that the perception of CV syllables may involve a process of analysis by feature. The performance on the steady state vowels, they suggested, is midpoint between music recognition and speech recognition.

The data presented by Shankweiler and Studdert-Kennedy are consistent with Kimura's (1967) suggestion that articulability is the critical feature. However, this data also implies that all speech sounds are not equally weighted. Studdert-Kennedy and Shankweiler (1970) attempted to examine this concept in greater detail by analyzing the components of the speech signal. The stimuli consisted of natural CVC syllables. A right ear preference was found for the initial and final stop consonants. However as in their previous study (Shankweiler & Studdert-Kennedy, 1967) no laterality effect was observed for the vowels. The articulatory features of voicing and place produced a right ear preference, however the authors suggested that the features are processed separately and that voicing values are more accurately identified than place.

Studdert-Kennedy and Shankweiler (1970) supported a perceptual model such as the one developed by Kimura (1961b), stating that the right ear preference is the result of superior contralateral pathways while the left ear input must follow a less direct path to the dominant hemisphere. They have also suggested that the left and right ear inputs converge at some point before combination of features into a single message and it is for this process of feature extraction that the left hemisphere is dominant. They assigned to the left hemisphere that portion of the perceptual process which is linguistic, i.e., the extraction of auditory stimuli into phonological features. They argue that the value of the speech material is not its acoustic structure, rather it is the phonological information they conveyed. The stimulus material used in the above discussed Gerber and Goldman (1971) study was the same as that employed in the Shankweiler and Studdert-Kennedy (1967) study. Gerber and Goldman found that consonant pairs which differed on only one articulatory feature, either voicing or place, were most easily identified. These data are consistent with those reported by Shankweiler and Studdert-Kennedy.

Spreen and Boucher (1970) have also suggested that there may be qualitative differences within language stimuli. These authors reasoned that since speech is dependent on the frequency characteristics of the signal it should be expected that if the higher frequencies were filtered out of words, the consonants of the speech signal would be affected. With successive amounts of filtering the speech signal could be reduced to vowel components. Four levels of low pass filtering were employed: 2.5, 2, 1.5, and 1 kHz. As hypothesized, successive levels of filtering eliminated the previously established right ear preference. Spreen and Boucher interpreted their data as consistent with Shankweiler and Studdert-Kennedy and suggested that the right ear preference is a language related phenomenon which disappears as sounds become more dissimilar from normal speech. Kirstein (1970) has argued that the lack of lateralization found with dichotic presentation of vowels may indicate that vowels are inconsistently analyzed by speech processes in the left hemisphere and non-language processes in the right hemisphere.

Spellacy and Blumstein (1970a, 1970b) have argued that even though vowel sounds convey less information than consonants they are considered phonemic by linguists and according to the perceptual model should elicit a right ear preference, perhaps to a lesser extent than consonants. By manipulating the S's expectation, these authors hypothesized that if Ss attended to vowel sounds as language, a right ear preference should be observed, while if Ss attended to vowel sounds as meaningful non-language sounds, a left ear preference would be observed. To test this hypothesis, Ss listened to vowel sounds in a language and non-language context. The stimulus material in the language condition consisted of CVC real words and nonsense words. The CVC words differed in their initial consonant or in their medial vowel in the dichotic presentation. In the non-language condition, CVC nonsense words were used with an equal number of non-language sounds such as melodies and sound effects. As hypothesized, the consonants showed a right ear preference in both conditions. With the vowels however, a right ear preference was found in the language group while a left ear preference was found in the non-language group. The reversal in ear preference was due to language set and such a preference for vowels, either with the right or left ear, had not previously been reported.

Considering these data, Spellacy and Blumstein (1970a, 1970b, 1970c) argued that the notion of a simple distinction of function or of bilateral asymmetry was questionable for two reasons. In the first place, if manipulation of language set in the non-language condition produced a left ear preference for vowels, then it was reasonable to assume that the same should be true for consonants, which was not the case. The second problem for the bilateral model was found in the fact that the left ear performance for vowels was the same in both the language and non-language conditions. It appeared that the switch from right to left ear preference in the non-language condition did not arise from an increased efficiency of the left ear but rather from a decreased efficiency of the right ear.

Darwin (1969) dichotically presented Ss with fricatives and noted that the Ss performed equally well with either ear. Darwin suggested that speech sounds will only show a right ear preference when they contain certain formant transitions. Following this notion, Spellacy and Blumstein suggested that it may be the frequencies which are associated with the transition from consonants to vowels which give rise to the right ear preference. When vowels are attended to as language sounds this transition enhances perception, however when not attended to as language sounds the transition inhibits perception. Spellacy and Blumstein further argue that their data required an explanation which accounts for a selective attention phenomenon which can affect a right ear recognition of vowel varied syllables but have no effect on consonant varied syllables. They argued that the role of the left hemisphere in speech perception is associated with perception of acoustic speech frequencies. When auditory stimuli are not attended to as language sounds the ability to detect such critical frequencies is decreased. Therefore, the left ear preference which has been demonstrated for certain non-language sounds may be explained in terms of a decrease in left hemisphere perception rather than a right hemisphere dominance.

In a more recent investigation of ear asymmetries to vowel sounds, Weiss and House (1973) dichotically presented vowels to Ss at signal to noise ratios of 0 and -10 dB. Under the easier listening condition, i.e. 0 dB signal to noise ratio, no ear differences were found and Ss were quite successful in recognizing the sounds presented to both ears. However, under the more difficult listening condition, i.e. -10 dB signal to noise ratio, the right ear was preferred to the left ear. Furthermore, the authors noted that the Ss tended to recognize only one of the sounds and when two were recognized one of them was usually wrong. Weiss and House also found that in spite of the fact that the vowel sounds were matched for amplitude and duration they were not equally perceptible. Those vowels which are usually described as being more intelligible under standard articulation test conditions tended to be heard most successfully. The authors conclude that these data support the view that various speech signals are not processed in different parts of the cerebral cortex. Considering the position of Spellacy and Blumstein it could be argued that the Ss in the Weiss and House study were being tested in a context in which they attended to the vowels as speech sounds. With the 0 dB signal to noise ratio condition the task was too easy and Ss were capable of recognizing both signals. As the task became more difficult the laterality effect was observed.

Halperin, Nachshon, and Carmon (1973) have presented data which refute the concept of a verbal-non-verbal continuum. The Ss were tested with two different dichotic listening tasks, each of which employed tonal sequences. In one test the tonal patterns varied in terms of frequency (either high or low) and in the other the variation was in terms of stimulus duration (either long or short). Each tonal pattern was composed of three elements. Within each tonal pattern there were three possible transitions: zero, one, or two. For example, in the frequency test, zero transitions would consist of three high or three low tones (e.g. HHH); one transition could be represented by one high tone and two low tones (e.g. HLL); and two transitions could be represented by a high tone followed by a low tone followed by a high tone (e.g. HLH). Halperin et al. found that with zero transitions there was a left ear preference for both tonal tests. However, with an increase from zero to two transitions there was a shift from left to right ear preference. The authors note that these data are inconsistent with Kimura's division of function of the two hemispheres and suggest that the left hemisphere is dominant in the processing of temporal patterns and that the perception of verbal stimuli may be associated with the sequential analysis of the acoustic stimuli.

Spellacy and Blumstein (1970b, 1970c) questioned the notion of bilateral hemisphere dominance in auditory perception and suggested that auditory perception is a function of a single active hemisphere which is involved in both speech and non-speech sounds. The degree of involvement varies with the nature of the auditory stimuli and thus contributes to a left or right ear preference. The notion that frequency transitions are the critical characteristics in right ear preference for verbal sounds was further supported by the Spreen and Boucher (1970) study. Perhaps one of the most interesting implications from these studies by Spellacy and Blumstein concerns the concept of a single active hemisphere in auditory perception. A language-non-language distinction is maintained but this distinction does not imply the involvement of the left or right hemisphere.

Further support for this concept of a single active hemisphere is provided by the Haydon and Spellacy (1973) study cited above. In that study it will be recalled that when Ss were uncertain as to which ear was to be stimulated RTs to right ear stimulation were considerably faster than those for left ear stimulation. This finding was observed for both speech sounds and pure tones. Haydon and Spellacy noted that the finding of a right ear preference for speech sounds is consistent with the literature relating language perception and cerebral dominance. However, the finding that the right ear preference obtains also for tones suggested that the left hemisphere plays a major role in the perception of some non-speech sounds when the Ss' expectations were manipulated. These authors concluded that the right ear preference for language perception reflects, in part, an attentional process. As an alternative, they argued that such attention is language mediated, thus creating the right ear preference for essentially meaningless, non-language tones.

Development of the Hypotheses

From the preceding literature review a few summary statements can be drawn: (a) laterality effects do occur in auditory perception; (b) a right ear preference has been observed for language sounds and this has been attributed to a left hemisphere dominance for speech perception and the superiority of the contralateral auditory pathways; (c) a left ear preference has been observed for certain non-language sounds and this has been attributed to a right hemisphere dominance for the perception of these non-language sounds and the superiority of the contralateral auditory pathways and; (d) based on empirical evidence, recent investigators have questioned the notion of a simple bilateral hemispheric specialization.

Perhaps the most compelling psychological evidence for a right ear, left hemisphere dominance for language material comes from those studies in which order of report is controlled. In the experiments reported above by Bryden (1967), Satz et al. (1965), Bartz et al. (1967), Borkowski et al. (1965), and Goodglass and Peck (1972), it has been noted that while the right ear is more frequently preferred as the immediate recall channel, it is also more efficient when used as the storage channel in situations where the Ss are required to recall from the left channel first. The implications from these data are that verbal material which is presented to the right ear and reaches the dominant left hemisphere is very efficiently coded either for immediate recall or for temporary storage. Unfortunately no data has yet been presented in which order of report is controlled with non-language sounds used as the stimuli. It would be interesting to see if non-language sounds presented to the left ear were coded as efficiently, either for immediate or delayed recall. In the present study Ss are presented with two different dichotic listening tasks; one which involves the dichotic presentation of speech sounds or one which involves the dichotic presentation of non-language sounds. In both cases order of report is controlled with Ss reporting the left and right ears first an equal number of times. However, before the hypotheses can be more fully developed a major methodological issue must be discussed.

Recall versus recognition: In the majority of dichotic listening studies cited above in which the stimulus was verbal in nature the Ss were presented with a dichotic pair or sets of pairs and asked to repeat as many of the stimulus sounds as they could remember. This is a recall task. With the presentation of non-language stimuli, the Ss are typically presented with a single dichotic pair followed by foils of stimulus sounds and the Ss are then asked to identify which members of the foils constituted the original dichotic stimulus. This is a recognition task. Kintsch (1970) has pointed out that recall and recognition are not identical tasks and that each one places different demands on the S. Generally speaking, recognition is usually superior to recall, however exceptions have been noted. This is particularly interesting since many researchers have been unable to demonstrate a left ear preference for non-language sounds. According to Kintsch, the most frequent explanation for the superiority of recognition over recall is due to recognition on the basis of partial cues. In order to recall stimuli correctly, all of the information must be stored in memory, or at least enough of it to permit reconstruction. With a recognition task however, it is possible to recognize stimuli by responding to partial cues. The usual superiority of recognition over recall has, however, on occasion been observed in reverse. Kintsch cited a study by Bruce and Cofer in which the distractor items in the recognition foils were highly similar to the target items. Under this condition, task difficulty was increased and Ss who were permitted to use the recall procedure obtained better scores.

This distinction between recognition and recall raises the question of whether the same results would have been obtained if researchers using dichotic verbal stimuli had employed a recognition task as opposed to a recall task. Conversely, the question is raised of whether the same results would have been obtained if researchers using dichotic non-language stimuli had employed a recall task as opposed to a recognition task. Recalling non-language stimuli presents many obvious problems perhaps explaining why the recognition task is employed with non-language stimuli.

With verbal material it is possible to use either a recall or recognition task although, as noted above, most researchers prefer to use the recall task. Broadbent and Gregory (1964) attempted to provide an answer to the question of whether the same results would be obtained if a recognition task were employed. The Ss were dichotically presented with three pairs of digits. Following the dichotic presentation the Ss were binaurally presented with four groups of three digits; one corresponding to the group heard at the left ear and one corresponding to the group heard at the right ear. Broadbent and Gregory found that Ss were less accurate in recognizing information presented to the left ear than to the right and concluded that the observed ear asymmetries could not be attributed to the testing technique. Similarly, Springer (1971) presented Ss with dichotic pairs of CV syllables and asked them to monitor for the presence of a target CV syllable which could occur in either ear. The Ss were asked to respond by depressing a RT key whenever the target sound occurred. Springer found the Ss had faster RTs when the target was presented to the right ear than when it was presented to the left ear. While this is more of a detection task than a recognition task it provides further support for the notion that laterality effects are not a direct result of the testing procedure.

That the recognition procedure would also reveal a right ear preference when sounds presented to the right ear were to be stored has not been formally reported. However, pilot data collected in connection with the present study revealed a right ear preference when the right ear was used as the immediate recognition channel as well as when sounds presented to the right ear were to be stored. These Ss were presented dichotically with a single pair of CV sounds followed by monaural recognition foils to either the right ear first followed by the left ear or vice versa. The Ss did not know in advance to which ear the recognition foils would appear first. For a more complete discussion of the methods and results of this pilot study the reader is referred to Appendix A. These data provide further support for Broadbent and Gregory's (1964) notion that laterality effects are not a function of testing technique.

The hypotheses: The widely replicated finding of Kimura's of a right ear preference in auditory perception for speech sounds rests on the assumptions that contralateral afferents are superior to ipsilateral afferents and that the left hemisphere is in some way specially organized for speech discrimination and recall. While the majority of research supports this position, there is a problem in the logic. Most of the studies reported thus far have employed spoken free recall as the response yet speech production is a well documented function of the left hemisphere. Therefore the question arises as to whether the right ear preference is the result of a perceptual superiority of the left hemisphere or because there is a differential bias to the right ear since a verbal response is required. This problem has been addressed by Inglis (1968). One solution to this problem would be to employ a recognition task rather than a recall task. A recognition task does not employ the same level of verbal encoding as does a recall task. Any ear differences observed with a recognition task might be more representative of the perceptual capacities of the left and right hemispheres.

The majority of studies which have employed a recognition task have not attempted to control for the order of recognition. (This presents a problem in interpreting such research.) If sounds presented to one ear are to be stored in some way while the S is attempting to recognize sounds presented to the other ear then one might expect there to be some decay in the sounds which are to be stored. Thus the issue of short term memory is raised. This criticism also has been made by Inglis who, as noted above, has argued that order of report is the most important variable in dichotic listening studies. If, on the other hand, one hemisphere was superior in the perception of a certain type of sound, then the decay of the memory trace should be less for information presented to the contralateral than to the ipsilateral ear.

One final issue must be considered before the hypotheses are offered. Following the demonstration of a left ear preference for music recognition, Kimura proposed an explanatory model based on bilateral asymmetry of function. This model holds that the left hemisphere is specially organized for the perception of speech sounds while the right hemisphere is organized in an analogous manner for the perception of non-verbal sounds. It must be noted that the concept "non-verbal" has not been adequately defined, and the effect itself has been difficult to demonstrate. If everything which is not speech is considered non-verbal, then the research findings cited above would lead to the conclusion that a right hemisphere dominance for all non-verbal sounds does not exist. Rather than accept such a conclusion it seems probable that right hemisphere dominance is related to a still undefined class of sounds.

The present experiment is concerned with the perceptual and memory capacities of the left and right hemispheres in man as well as the interaction between perception and memory. The Ss are dichotically presented with a verbal and non-language test in which recognition is required and order of recognition is controlled. The terms verbal and non-language are used instead of verbal and non-verbal or language and non-language to avoid confusion with previous usage. Verbal describes stimulus sounds (i.e. CV syllables) which are not meaningful language sounds but are parts of words. Non-language describes stimulus sounds which are not created by a human voice. This is to be contrasted with Kimura's use of non-verbal to describe stimuli which were emotional sounds or hummed melodies produced by humans but which were not words. Controlling order of recognition has the advantage of not only providing an estimate of perception and memory of sounds presented to the left and right ears, but also requires Ss to localize from an array which sound was presented to which ear.

Considering the above discussion, three sets of hypotheses are offered. One set is concerned with perception, another set is in the area of memory, and the final set is concerned with the interaction between perception and memory. The hypotheses are as follows:

1. Perceptual performance for the right ear will be superior

to that of the left ear for verbal sounds.
(a) This finding should be observed for immediate recognition and, (b) for delayed recognition.

2. Perceptual performance for the left ear will be superior to that of the right ear for non-language sounds.
(a) This finding should be observed for immediate recognition and, (b) for delayed recognition.

3. (a) Verbal sounds presented for immediate recognition to the right ear will be recognized more accurately than verbal sounds which are presented to the right ear for delayed recognition.
(b) Verbal sounds presented for immediate recognition to the left ear will be recognized more accurately than verbal sounds which are presented to the left ear for delayed recognition.

4. (a) Non-language sounds presented for immediate recognition to the right ear will be recognized more accurately than non-language sounds which are presented to the right ear for delayed recognition.
(b) Non-language sounds presented for immediate recognition to the left ear will be recognized more accurately than non-language sounds which are presented to the left ear for delayed recognition.

5. The decrement in performance of the right ear for delayed recognition as opposed to immediate recognition will be less than the decrement of the left ear for delayed

recognition as opposed to immediate recognition when <u>S</u>s are presented with speech sounds.

6. The decrement in performance of the left ear for delayed recognition as opposed to immediate recognition will be less than the decrement of the right ear for delayed recognition as opposed to immediate recognition when <u>S</u>s are presented with non-language sounds.

Method

Subjects

The *S*s were 48 right handed female college students with a mean age of 18 years, 9 months (range 16 years, 10 months to 22 years, 1 month). The *S*s had not previously participated in dichotic listening studies. Right handedness was defined by a minimum of eight out of ten positive right hand responses on a questionnaire for manual preference (Spreen & Benton, 1969). No *S* reported any known hearing impairment.

Test Conditions and Experimental Procedure

The *S*s were randomly assigned to one of two dichotic listening test situations: verbal sounds and non-language sounds. Within both of these conditions all *S*s were tested for two levels of order of report for both the left and right ear. Both of these sound conditions, the order of report condition and the general stimulus paradigm, are discussed separately.

Verbal sound condition. The verbal sound condition consisted of the dichotic presentation of CV syllables. Six stop consonants were used and all were paired with the vowel "a." The six CV sounds used were ba, ta, ga, da, ka, and pa. Previous research by Studdert-Kennedy and Shankweiler (1970) and Gerber and Goldman (1971) has shown these sounds to be very effective in eliciting a right ear preference. Each syllable of the dichotic pair was recorded on a separate channel of magnetic recording tape such that the two syllables had simultaneous onset. Each trial consisted of a single pair of two different CV sounds. No CV syllable was paired with itself. The dichotic listening tape employed in the verbal sound condition was a modified copy of a tape originally constructed by Dr. Sheila Blumstein at the Haskins Laboratory. There were fifteen different stimulus pairings on this tape. The degree of simultanicity on this copy ranged from 0 msecs. to 30 msecs. with a mean of 9.0 msecs. Only two sounds exceeded 10 msecs. This measurement was made by visual inspection of oscilloscope patterns using the initial deviation from a flat tone as criterion for word onset.

Non-language sound condition. As with the verbal sound condition, six non-language sounds were used. To avoid possible S biases due to the verbal labelling of these non-language sounds, auditory stimuli from the same class were selected. Gordon (1970), it will be recalled, found no ear asymmetry in a dichotic melodies test in which the tones were largely devoid of timbre and chordal variation. However, in dichotic tests in which the stimuli were composed of chords which were rich in overtones, a significant left ear preference was found. Therefore, the present study employed six different chord-like sounds. The sound patterns were generated by an ARP Synthesizer Model 2600. Each of the sounds were quite distinct, with each being composed of three different tones. The tones were all generated by the saw-tooth and triangle generators of the Synthesizer as these sounds are believed to be the richest in overtones. The various frequencies of each of the components of the six sounds are presented in Table 1. As in the verbal condition, each sound was recorded on a separate channel of magnetic recording tape such that the sounds had simultaneous onset. Each trial consisted of a single pair of two different chords. No sound was paired with itself. As measured by an oscilloscope, the degree of simultanicity for thirteen of the fifteen dichotic pairs was 0 msecs. For the remaining two the degree of simultanicity was 5 msecs. and 10 msecs. respectively. Figure 1 presents spectograms of the six different chords.

Order of recognition. Ear order of recognition was controlled. On half of the trials six monaural recognition foils were presented to the left ear first followed by six monaural recognition foils presented to the right ear. This was referred to as Order I and was designated L_1R_2. On the remaining half of the trials, the recognition foils were presented to the right ear first followed by recognition foils to the left ear. This was referred to as Order II and was designated R_1L_2. For each Order condition a left and right ear score was obtained. The dependent measure was the number of correctly recognized sounds for each ear under each Order condition.

TABLE 1

Frequency Components of Each of the Six Sounds Used in the Non-Language Condition

Chord No.	Component	Frequency Hz
	1	267
I	2	801
	3	59
	1	60
II	2	4765
	3	495
	1	1074
III	2	619
	3	8956
	1	27
IV	2	190
	3	249
	1	29
V	2	2402
	3	3720
	1	309
VI	2	1936
	3	12762

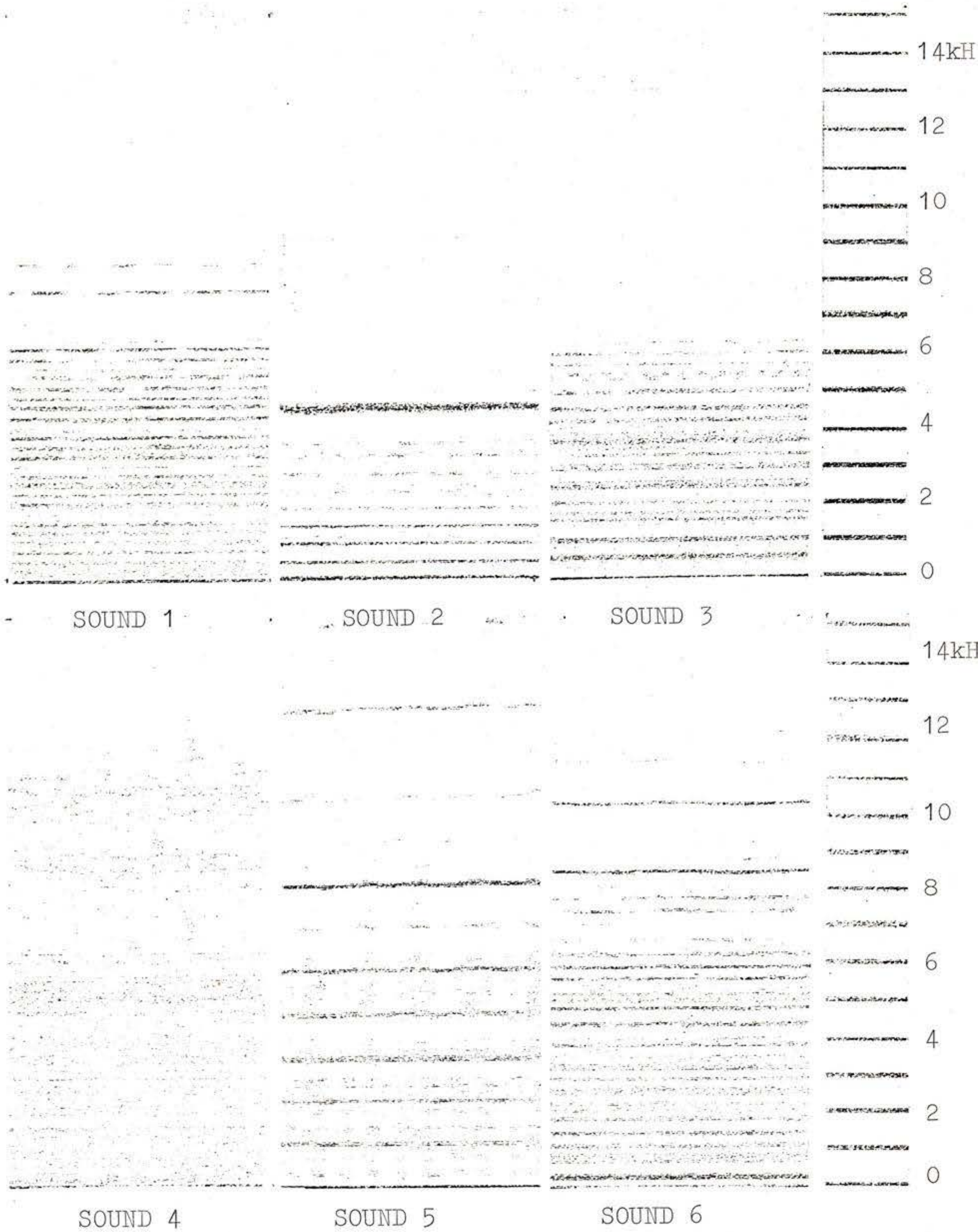

FIGURE 1. Spectograms of the six sounds used in the non-language sound condition.

The monaural recognition foils contained all six of the stimuli used in each sound condition (i.e. all six CV sounds or all six chords) and were presented in random order for each trial. The chance probability that the correct response would occur in any one of the six possible positions was one-sixth.

Stimulus paradigm. Prior to testing, all Ss were twice presented binaurally with the six sounds (either CV sounds or chord-like sounds) and were informed that these were the sounds used in this experiment. After binaural presentation of the six stimulus sounds, Ss were given four practice trials. On two of the practice trials, Order I (i.e. L_1R_2) was followed and on the remaining two practice trials, Order II (i.e. R_1L_2) was followed.

During the test session sixty trials were presented at an intensity of approximately 65 dB via a Sony TC 650 stereo tape recorder as the Ss listened through Koss KO 727b stereo headphones (ISO, 1969). In the dichotic pairs each CV sound and each chord-like sound occurred ten times to both the left and right ear. The trials were consecutively numbered binaurally. These spoken numbers served as a ready signal to the S. A graphic illustration of the stimulus paradigm employed in this study is presented in Figure 2. Approximately three seconds after the dichotic pair the monaural recognition foils were presented to either the right or left ear, according to Order I or Order II. The

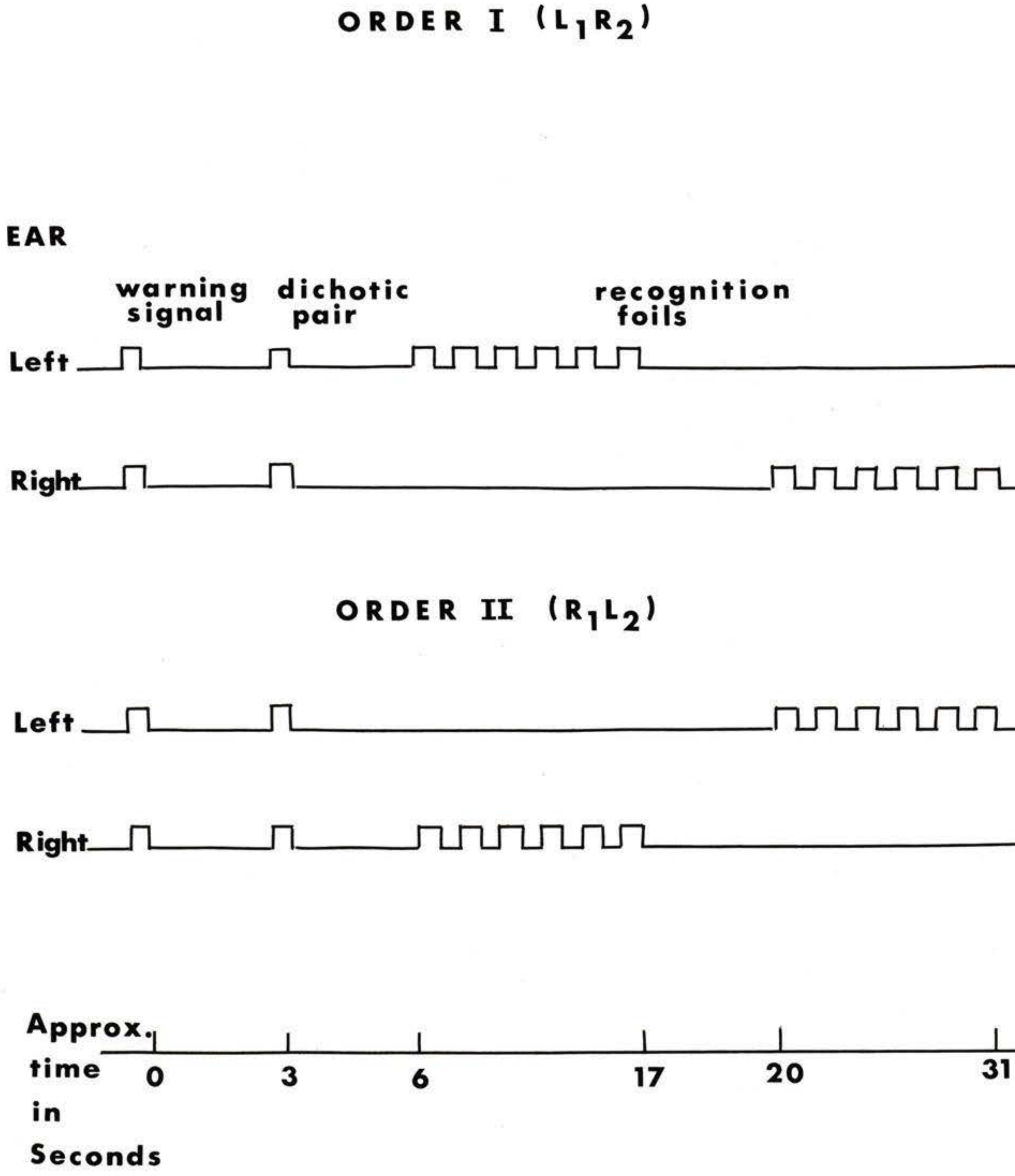

FIGURE 2. Illustration of the stimulus paradigm for both Order conditions for the verbal and non-language stimulus conditions.

S's task was to listen to each of the six foils and to say "yes" when they thought they had correctly recognized the sound presented to that ear. The Ss were instructed that during recognition all six of the sounds used in the study would be presented and the Ss could say "yes" as many times as they wished. However, Ss were cautioned that only their last "yes" answer would be accepted as their attempt at correct recognition. This feature was added so Ss could attempt self-correction if they felt they had previously made a mistake.

Approximately three seconds after completion of the first recognition foils and approximately twenty seconds following the ready signal, a second set of foils also containing all of the six CV sounds or chord-like sounds was presented to the opposite ear. The instructions remained the same; Ss were to say "yes" when they thought they had correctly recognized the sound presented to that ear. The monaural recognition foils for both the verbal and non-language conditions were presented at a rapid rate with a stimulus sound appearing at a rate of approximately one every 1.7 seconds. The inter trial interval (i.e. from the offset of one ready signal to the onset of the next ready signal) for both sound conditions was approximately 35 seconds.

Results

The data were treated by analysis of variance (ANOVA). Type of sound condition, i.e. verbal or non-language, was a between group variable while order of report and ear of stimulation were within group variables. Thus, the design was a two sounds by two orders by two ears factorial. The dependent measure was number of correctly recognized sound stimuli for the left and right ears.

In general, it was found that Ss recognized significantly more of the non-language sounds than the verbal sounds (56.8% vs. 42.1%). It was also found that the right ear was more efficient than the left ear regardless of sound class (54.9% vs. 44.1%). Statistically the above findings are supported by a sound main effect ($F_{1,46}=17.23$, $p<.001$) and by an ear main effect ($F_{1,46}=58.79$, $p<.0001$). The order main effect was not significant. The findings germane to the hypotheses are contained within the interactions and are discussed separately for both the verbal and non-language conditions.

Verbal Sound Condition

As hypothesized, Ss recognized more sounds presented to their right ear than to their left ear. This was observed for both order conditions. In Order I, in which the foils were presented first to the left ear and then to the right ear, Ss recognized 47.9% of the sounds presented to the right ear and 38.3% of the sounds presented to the left ear.

Eighteen of the Ss showed a superior performance for stimuli presented to the right ear, four showed a superior performance for stimuli presented to the left ear, and there were two ties. In Order II, in which the foils were presented first to the right ear and then to the left ear, Ss recognized 54.2% of the sounds presented to the right ear and 27.9% of the sounds presented to the left ear. Twenty-three of the Ss showed a superior performance for stimuli presented to the right ear and one showed a superior performance for stimuli presented to the left ear. These findings are depicted in Figure 3 which also presents the data for the non-language condition. Statistically, these differences are significant: for Order I ($t_{24}=3.54$, $p<.01$) and for Order II ($t_{24}=9.67$, $p<.001$).

It was also found that when sounds presented to the right ear were to be recognized first performance was slightly superior to when sounds presented to the right ear were to be recognized second ($t_{24}=2.30$, $p<.05$). Similarly it was found that when sounds presented to the left ear were to be recognized first performance was superior to when sounds presented to the left ear were to be recognized second ($t_{24}=3.83$, $p<.001$). The percentage of correct scores for each condition and t values for the verbal and non-language comparisons are presented in Table 2.

Non-Language Sound Condition

The data for the non-language condition present as

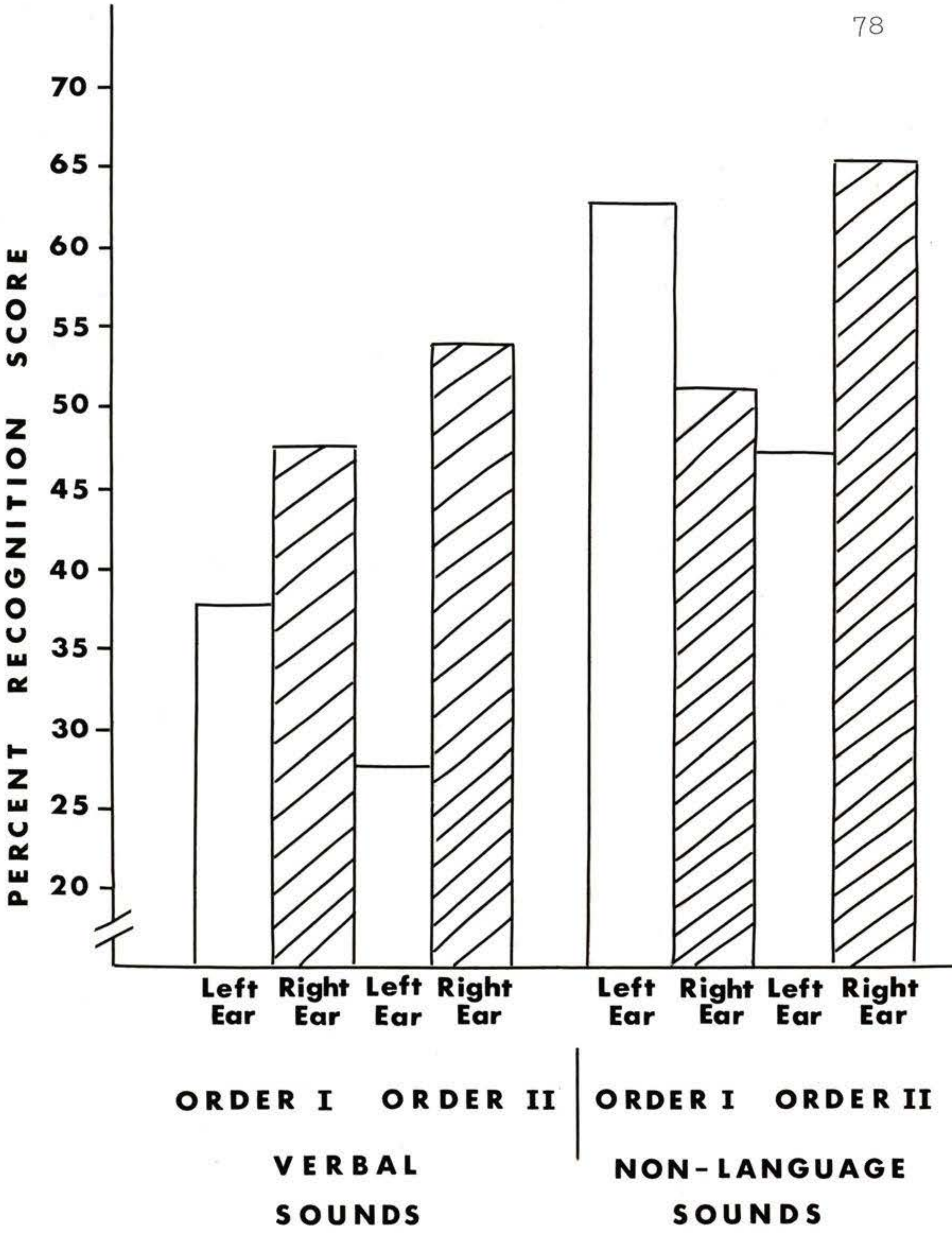

FIGURE 3. Per cent of correctly identified verbal and non-language sounds for the left and right ear for Order I (left ear recognition followed by right ear recognition) and Order II (right ear recognition followed by left ear recognition).

TABLE 2

Percentage of Correct Scores and t Values for

the Sound by Order by Ear Interaction

	Verbal Sounds					
	Left Ear	Right Ear	t Values	Left Ear	Right Ear	t Values
Order I	38.3	47.9	3.54**	62.7	51.5	4.14***
Order II	27.9	54.2	9.67***	47.2	65.8	6.86***
t Value	3.83***	2.30*		5.73***	5.27***	

* $p < .05$

** $p < .01$

*** $p < .001$

quite distinct from the verbal condition. The *Ss* were much more efficient in recognizing the foils which were presented first than those presented second, independent of ear. For Order I, i.e. left ear foils followed by right ear foils, *Ss* recognized 62.7% of the sounds presented to the left ear and 51.5% of the sounds presented to the right ear. For Order II, *Ss* recognized 65.8% of the sounds presented to the right ear and 47.2% of the sounds presented to the left ear. These findings are depicted in Figure 2. Statistically, these differences are quite convincing: for Order I (t_{24}=4.14, p<.001) and for Order II (t_{24}=6.86, p<.001).

It was also found that when sounds presented to the right ear were to be recognized first, performance was considerably better than when sounds presented to the right ear were to be recognized second (t_{24}=5.27, p<.001). Similarly, when sounds presented to the left ear were to be recognized first, performance was better than when sounds presented to the left ear were to be recognized second (t_{24}=5.73, p<.001). An interesting but non-significant trend was also noted in the non-language condition. The right ear was slightly preferred to the left ear when both were used as the first ear of recognition (65.8% vs. 62.7%). Similarly, the right ear was slightly preferred to the left ear when sounds presented to both were to be stored (51.5% vs. 47.2%). The percentage scores and t values for the non-language condition are presented in Table 2. The data for the verbal and non-language sound conditions were supported by a significant order by ear by sound interaction ($F_{1,46}$=5.90, p<.01).

A test of the homogeneity of the covariance matrix for the three way interaction proved non-significant (X^2_8=11.52, p>.17). Thus, the assumption of homogeneity of variance was not violated. The summary table for the three factor ANOVA is presented in Table 3.

Other Pertinent Findings

In addition to the above findings pertaining to the hypotheses of this study, two other interactions were found which are particularly interesting. Each of these interactions are discussed separately.

Order by ear interaction. This interaction, which is collapsed across the verbal and non-language sound conditions, reveals that when Ss employed Order I, i.e. left ear recognized first followed by right ear recognition, there was little difference in the performance of the two ears (left ear, 50.6% vs. right ear 49.7%). However, when Order II was employed, i.e. right ear recognized first followed by left ear recognition, the right ear was preferred to the left ear (right ear, 60.0% vs. left ear 37.6%). This interaction is illustrated in Figure 4. Statistically, Order II proved to be highly significant (t_{48}=11.68, p<.001). As with the above discussed three way interaction, this two way interaction also showed that the

TABLE 3

Analysis of Variance Summary Table for the

Three Factors: Sound, Order, and Ear

Source	df	Mean Square	F
Sound	1	940.76	17.23**
Error	46	54.61	
Order	1	7.92	1.14
Order x Sound	1	2.30	.33
Error	46	6.97	
Ear	1	503.76	58.79***
Ear x Sound	1	218.88	25.55***
Error	46		
Order x Ear	1	584.51	73.41***
Order x Ear x Sound	1	47.01	5.90*
Error	46	7.96	
Total	144		

* $p < .01$

** $p < .001$

*** $p < .0001$

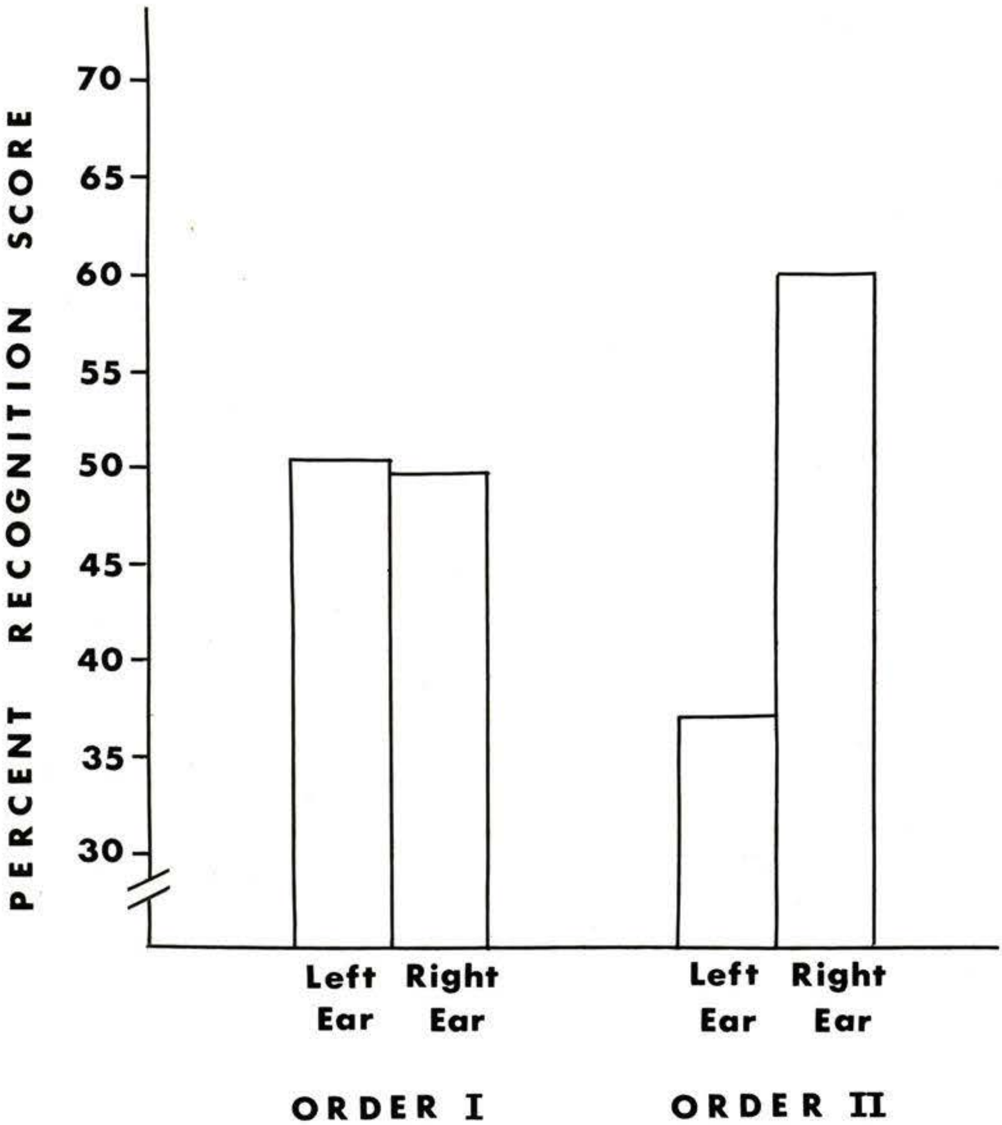

FIGURE 4. Per cent of correctly identified verbal and non-language sounds by the left and right ear for Order I (left ear recognition followed by right ear recognition) and Order II (right ear recognition followed by left ear recognition).

right ear was preferred when sounds presented were to be recognized first than when sounds presented were to be stored ($\underline{t}_{48}$=5.35, $\underline{p}$<.001). Similarly, the left ear was preferred when sounds presented were to be recognized first than when sounds presented were to be stored ($\underline{t}_{48}$=6.77, $\underline{p}$<.001). Of further interest was the finding that the right ear was preferred to the left ear when both had the opportunity for first recognition ($\underline{t}_{48}$=4.91, $\underline{p}$<.001). The order by ear interaction was quite significant ($F_{1,46}$=73.41, $\underline{p}$<.0001), probably accounting for much of the variance in this study. The percentage scores and $\underline{t}$ values for this interaction are presented in Table 4.

Ear by sound interaction. This interaction which is collapsed across order shows no significant differences between the left and right ears for the non-language sound condition. As noted above, there was a slight trend favoring the right ear (right ear, 58.7% vs. left ear 55.0%). For the verbal sound condition the right ear was preferred to the left ear (51.0% vs. 33.1%). This interaction is depicted in Figure 5. Statistically the difference between the left and right ears in the verbal condition is ($\underline{t}_{48}$=8.99, $\underline{p}$<.001). This interaction also revealed that recognition scores in the non-language condition were better than recognition scores in the verbal condition for both the left and right ears; ($\underline{t}_{48}$=10.99, $\underline{p}$<.001) and ($\underline{t}_{48}$=3.84, $\underline{p}$<.001) respectively. The significance of this ear by sound

TABLE 4

Percentage Scores and t Values for the Order by Ear Interaction

	Left Ear	Right Ear	t Value
Order I	50.6	49.7	.43
Order II	37.6	60.0	11.68*
t Value	6.77*	5.35*	

* $p < .001$

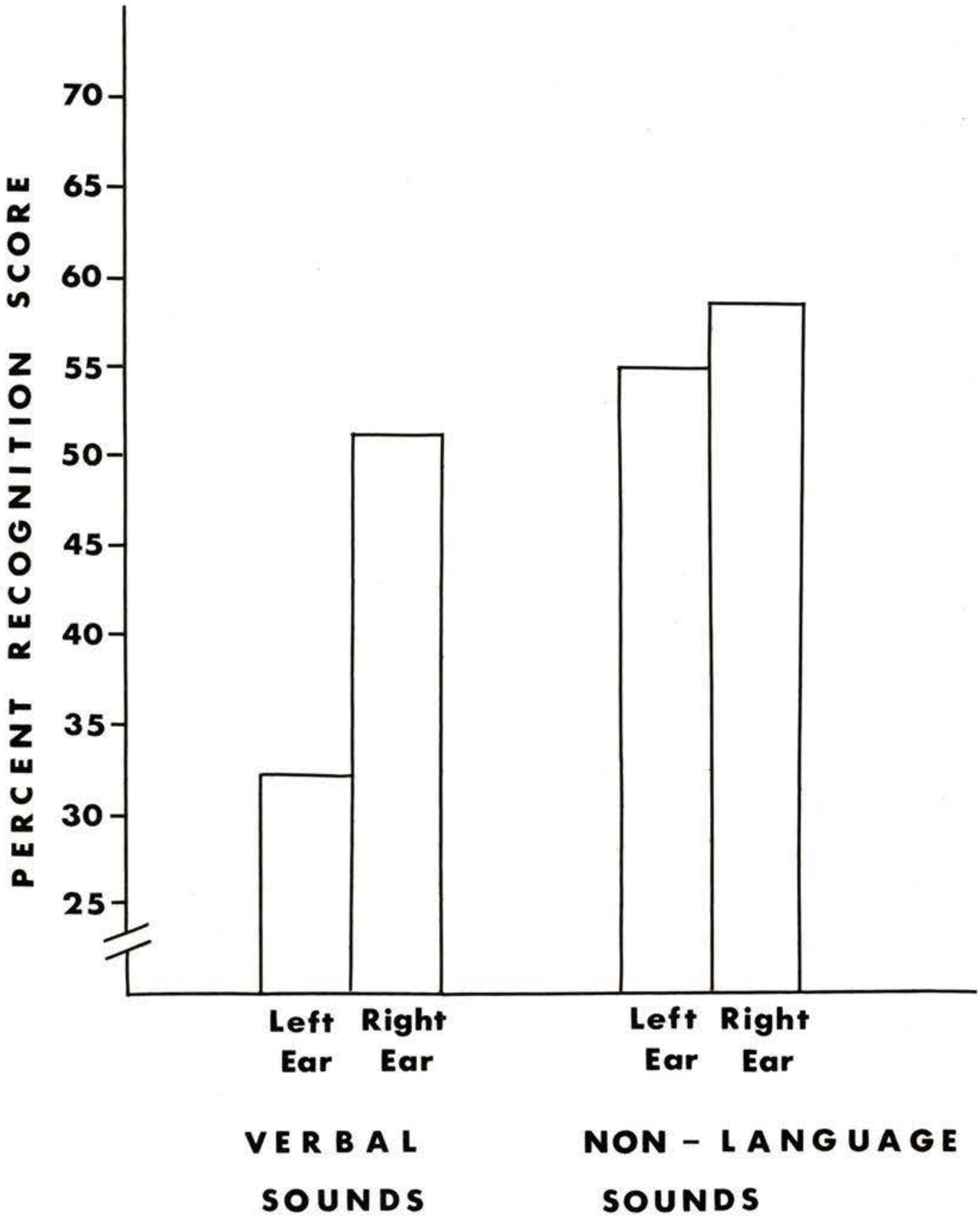

FIGURE 5. Per cent of correctly identified verbal and non-language sounds by the left and right ear for both order conditions.

interaction is ($F_{1,46}$=25.55, *p*<.0001). The percentage scores and *t* values are presented in Table 5.

TABLE 5

Percentage Scores and t Values for

the Sound by Ear Interaction

	Left Ear	Right Ear	t Value
Verbal Condition	33.1	51.0	8.99*
Non-Language Condition	55.0	58.7	1.84
t Value	10.99*	3.84*	

* $p < .001$

Discussion

The hypotheses of this study concerned the perceptual and memory capacities of the left and right hemispheres in man. Had all of these hypotheses been confirmed, considerable support would have been provided for the bilateral asymmetry of function model of the left and right hemispheres as proposed by Kimura and others. Since not all of the hypotheses were confirmed, the bilateral asymmetry of function model cannot be supported and alternative explanations must be considered. The findings are discussed in terms of the verbal and non-language sound conditions and the hypotheses of this study.

Verbal Sound Condition

It had been hypothesized that when Ss were presented with verbal sounds the right ear would be preferred when sounds were presented for immediate recognition as well as when sounds were presented which required storage into short term memory.

These hypotheses were most convincingly supported. That this was found when a recognition procedure was employed and order of recognition was controlled has not previously been reported. The most likely explanation for this finding of a right ear preference is to attribute it to the well documented role of the left hemisphere in speech perception and the superiority of the contralateral over ipsilateral pathways in auditory perception. Information presented to the right ear is very efficiently encoded either for immediate recognition or for storage for recognition at some later time. Sounds presented to the left ear are less efficiently encoded either for immediate recognition or for storage. One explanation for the inferior left ear performance would be the suppression of the ipsilateral pathways and the degradation of the neural signal resulting from the extra synaptic activity involved in crossing the corpus callosum and the fact that these callosal fibers are believed to terminate in the association areas as opposed to the primary receiving area (Geschwind, 1965). This interpretation is consistent with the modification of Kimura's perceptual model offered by Sparks et al. (1970).

The memory hypothesis held that when sounds which were to be stored were presented to the right ear, performance would be inferior to when sounds for immediate recognition were presented. Similarly, the same was predicted for the left ear, i.e. first recognition is better than second recognition. Those hypotheses were also confirmed which suggest that short term memory played an important role in this task. When sounds were presented for storage to the right ear there was a 6.3% decrement in performance as opposed to when sounds were presented to the right ear for immediate recognition. Similarly, when sounds were presented for storage to the left ear, there was a 10.4%

decrement in performance as opposed to when sounds were presented to the left ear for immediate recognition. The most likely explanation for this finding is probably a slight deterioration of verbal memory traces over prolonged periods of time in which rehearsal was not possible, or that previous recall interfered with the delayed recognition task.

Examination of Figure 2 clearly supports the hypothesis that perception and memory interact when Ss are presented with verbal stimuli. In the Order II condition (i.e. right ear recognition followed by left ear recognition) there was a 26.3% decrement in recognition by the left ear. However, in the Order I condition (i.e. left ear recognition followed by right ear recognition) there was a 9.6% increment in recognition. This is an impressive finding considering the difficulty of the task and the fact that as much as thirty seconds might have passed before the Ss had the opportunity for right ear recognition. Thus it would appear that the left hemisphere is not only dominant in the perception of verbal sounds but is also dominant in encoding of verbal memory traces for later recognition. Verbal sounds arriving in the left hemisphere via the contralateral right ear afferents are very efficiently processed.

Non-Language Sound Condition

Following the bilateral asymmetry of function model it was hypothesized that Ss would show a left ear preference regardless of whether sounds were presented to the left ear for storage or for immediate recognition. It was also hypothesized that there would be an interaction between the perception and the memory of these non-language sounds favoring the left ear and the right hemisphere. These hypotheses were not confirmed. Rather it was found that sounds presented for immediate recognition were recognized far more efficiently than those sounds which were presented for storage. In the Order I condition (i.e. left ear recognition followed by right ear recognition) there was an 11.2% decrement in sounds to be recognized by the right ear while in the Order II condition (i.e. right ear recognition followed by left ear recognition) there was an 18.6% decrement in sounds presented to the left ear. These data clearly suggest that there is no lateralization of either perceptual or memory processes for these non-language sounds. Such a position refutes the bilateral asymmetry of function model and suggests that different perceptual and memory processes are employed when certain non-language stimuli are dichotically presented.

The only hypotheses that were confirmed in the non-language sound condition were the memory hypotheses. These hypotheses held that when sounds which were to be stored were presented to the right ear, performance would be inferior to when sounds for immediate recognition were presented. Similarly, the same was predicted for the left ear, i.e. first recognition is better than second recognition. When sounds were presented to the right ear for storage, there was a 14.3% decrement in performance as opposed to when sounds were presented to the right ear for immediate recognition. When sounds were presented for storage to the left ear, there was a 15.5% decrement in performance as opposed to when sounds were presented for immediate recognition.

The most likely explanation for these data holds that both hemispheres participate to a relatively equal extent in the perception of these non-language sounds. Support for this position is provided by the ear by sound interaction. This interaction showed no significant differences between the left and right ears in the recognition of non-language sounds. However, when verbal sounds were presented, right ear recognition was considerably better than left ear recognition. This suggests that either hemisphere is capable of recognizing non-language sounds whereas the left hemisphere is considerably better than the right in the recognition of verbal sounds. It would also appear that both hemispheres participate to a relatively equal extent in the memory of these non-language sounds. However, those regions of the two hemispheres in which the memory trace is to be stored is less well developed than the region within the left hemisphere which is responsible for the storage of verbal memory traces. The memory trace for these non-language sounds, unstably coded, is subject to rapid decay with time or as the result of interference. It must be noted, however, that the ear to which sounds were presented for storage, either left or right, obtained recognition scores of approximately 50.0%, suggesting that the non-language sounds were more easily recognized than the verbal sounds. This interpretation is further supported by the sound main effect which showed non-language sound recognition to be better than verbal sound recognition.

The fact that non-language sounds were recognized more accurately than verbal sounds, independent of ear, is an interesting finding. One possible explanation is that it is easier to identify the ear of arrival of the non-language sounds than it is for the verbal sounds. Since the non-language sounds and the verbal sounds were of approximately the same duration it may be that the critical features for distinguishing the non-language sounds are considerably longer than the brief noise bursts and transitions that serve to distinguish the six stop consonants. Following this reasoning, the non-language sounds would be more easily localized than the CV syllables which vary only in the consonant thus accounting for easier recognition.

This interpretation of the superiority of recognition of the non-language sounds over the verbal sounds is not at variance with the notion that both hemispheres participate to an equal extent in the perception and memory of these non-language sounds. Rather it is suggested that both hemispheres are presented with more distinguishing critical features resulting in better recognition scores. The decrement in performance of the ear to which sounds were presented for storage is, as above, best explained in terms of a decay of the memory trace or as the result of stimulus interference.

The above interpretations for the non-language sound condition are at variance with the data presented by Gordon (1970) who found a left ear preference for chords rich in overtones. In the present study, synthetically produced sounds, which were also rich in overtones, were employed and a left ear preference was not found. Gordon, however, did not attempt to control ear order of recognition. Thus, it must be argued that the present interpretation of the non-language data supports Inglis' (1968) contention that order of report is the most critical variable in dichotic listening studies with the constraint that the stimulus material is non-language.

Summary

The hypotheses of this study concerned the perceptual and memory capacities of the left and right hemispheres in man. In the verbal sound condition all of the hypotheses were confirmed. These data were interpreted as providing further support for the role of the left hemisphere and the contralateral auditory pathways in auditory perception. That the right ear preference was still observed when verbal sounds presented to the right ear were to be stored was interpreted as supporting the notion that perception and memory interact and that the memory for verbal sounds is also a left hemisphere process. That these data were obtained with a recognition task with order controlled suggests that spoken recall is not a critical variable when verbal materials are dichotically presented.

Most of the hypotheses for the non-language sound condition were not confirmed. Rather it was found that first ear of recognition was superior regardless of whether it was the left or right ear. These data were interpreted as reflecting an equipotentiality of both hemispheres in the recognition of these non-language sounds and further suggests that the order of report is the most important variable in invluencing this recognition in the present study. There was no evidence for a right hemisphere dominance in the perception or memory of these non-language sounds. This interpretation is consistent with Inglis' (1968) findings and interpretation. Considering the superior recognition of the non-language sounds when compared with the verbal sounds it is suggested that the non-language sounds presented more distinguishable critical features than the CV sounds, thus enhancing perception and memory. Perhaps the most important implication from these data for future research is that they suggest a different organization in memory for verbal and non-language sounds.

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APPENDIX A

Pilot Study: Dichotically Presented Verbal Sounds in Which a Recognition Task was Employed and Order was Controlled

Introduction

The purpose of this pilot study was to determine whether dichotically presented CV sounds would elicit a right ear preference under two conditions: when Ss heard recognition foils presented first to the left ear followed by the right ear and when Ss heard recognition foils presented first to the right ear followed by the left ear.

Method

Subjects

The Ss were five male and five female graduate students at the University of Victoria. All Ss reported themselves as strongly right handed and no S reported any hearing impairment.

Test Condition and Experimental Procedure

The test conditions and experimental procedures were identical to those described in the verbal sound condition in the method section of the main body of this paper. The only exception was that only thirty of the total of sixty trials were administered.

Results

The data were treated by analysis of variance (ANOVA). There were two levels of order of recognition: Order I, in which recognition foils were presented first to the left ear then to the right ear, and Order II, in which recognition foils were presented first to the right ear and then to the left ear. Order was a within group variable. Ear of stimulation was also a within group variable. Thus, the design was a two by two factorial. The dependent measure was the number of correctly recognized CV sounds for the left and right ears.

Analysis of these data revealed that when Ss employed Order I, i.e. left ear foils presented first followed by right ear foils, recognition scores for the right ear were superior to those for the left ear (48.7% vs. 38.7%). Similarly, when Ss employed Order II, i.e. right ear foils presented first followed by left ear foils, the recognition scores were also better for the right ear as opposed to the left ear (56.7% vs. 38.7%). Statistically, these differences are significant: for Order I ($t_9=3.57$, $p<.01$) and for Order II ($t_9=7.86$, $p<.001$). It was also found that when the right ear was recognized first it was slightly preferred to when it was recognized second ($t_9=2.86$, $p<.05$). The percentage scores and t values for these data are presented in Table 6. These data are supported by a significant order by ears interaction ($F_{1,9}=9.23$, $p<.01$). The summary table for this two factor ANOVA is presented in Table 7. This analysis also revealed a significant ears main effect ($F_{1,9}=5.67$, $p<.05$). The data for this pilot study are presented in Appendix B.

TABLE 6

Pilot Data: Percentage Scores and *t* Values for the Order by Ear Interaction

	Left Ear	Right Ear	*t* Value
Order I	38.7	48.7	3.57**
Order II	34.7	56.7	7.86***
t Value	1.43	2.86*	

* $p < .05$

** $p < .01$

*** $p < .001$

TABLE 7

Pilot Data: Analysis of Variance Summary Table
for the Two Factors, Order and Ear

Source	df	Mean Square	F
Order	1	.96	.16
Error	9	5.57	
Ear	1	57.60	5.67*
Error	9	10.16	
Order x Ear	1	8.10	9.23**
Error	9	.88	
Total	30		

* $p < .05$

** $p < .01$

Discussion

The finding of a right ear preference is consistent with the literature relating language perception to cerebral dominance. The most apparent explanation is to attribute the right ear preference to the well documented role of the left hemisphere in speech perception and the superior role of the contralateral auditory pathways. That these findings were obtained when a recognition task was employed and order of recognition controlled provides further support for the notion that laterality effects are not a direct result of testing procedure.

APPENDIX B

Pilot Study Data: Expressed in Terms of
Number of Correctly Recognized Stimulus Sounds

Ear		Order I		Order II	
		Left	Right	Left	Right
_S_s	1	6	10	5	8
	2	9	9	6	8
	3	5	4	9	10
	4	7	10	4	7
	5	3	7	2	7
	6	6	6	5	7
	7	4	7	4	10
	8	1	10	3	12
	9	10	6	10	10
	10	7	4	4	6

APPENDIX C

Ph.D. Study: Data Expressed in Terms of Number of Correctly Recognized Stimulus Sounds

Verbal Sound Condition					Non-Language Sound Condition				
	Order I		Order II			Order I		Order II	
Ear	Left	Right	Left	Right	Ear	Left	Right	Left	Right
Ss					Ss				
1	11	11	2	15	25	17	10	7	13
2	3	12	6	15	26	17	12	12	16
3	8	10	8	19	27	23	13	12	23
4	6	14	7	13	28	24	22	24	24
5	17	22	16	20	29	22	21	20	21
6	10	16	6	18	30	24	19	13	27
7	9	15	6	8	31	19	14	15	13
8	7	13	10	16	32	16	13	10	17
9	6	14	9	20	33	18	13	10	20
10	13	13	8	18	34	22	17	15	26
11	12	14	13	21	35	20	17	14	18
12	20	22	14	23	36	16	17	21	23
13	15	21	10	25	37	20	21	16	18
14	7	8	4	15	38	21	18	18	25
15	13	16	6	13	39	15	11	15	18
16	15	10	13	11	40	5	5	5	11
17	15	13	11	14	41	28	23	25	25
18	14	17	5	21	42	16	10	10	16
19	18	17	15	19	43	24	14	10	25
20	12	14	6	14	44	27	19	18	22
21	7	14	4	19	45	14	12	8	17
22	12	11	6	10	46	13	17	18	17
23	12	13	10	11	47	14	13	7	18
24	13	15	6	12	48	21	20	17	19

APPENDIX D

Supplemental Analyses: Verbal Sound Condition

Introduction

Supplemental analyses were performed on the data from the verbal sound condition to determine which of the six CV sounds contributed the most to the laterality effect. The data were also analyzed to determine whether there was a serial order effect, i.e. did it make any difference whether the correct foil was in position one, two, three, etc.

Results and Discussion

Analysis of variance for the ear by syllable data showed that the right ear was preferred in the recognition of all sounds except da, which both ears were equally successful in perceiving. The dependent measure for this analysis was the number of correctly recognized syllables for the right and left ear. While the right ear was preferred in recognizing the remaining five CV sounds, the only sounds which proved to be statistically significant were ga ($\underline{t}_{24}=4.39$, $\underline{p}<.001$), ka ($\underline{t}_{24}=6.14$, $\underline{p}<.001$), and ta ($\underline{t}_{24}=7.41$, $\underline{p}<.001$). The pa and ba sounds fell slightly short of significance at the $\underline{p}<.05$ level. Mean scores and $\underline{t}$ values for these data are presented in Table 8. These data are supported by a significant ear by syllable interaction ($F_{5,115}=7.63$, $\underline{p}<.001$).

As is apparent from Table 8, the ta sound contributed the most to the laterality effect, with ka, ga, ba, and pa

TABLE 8

Mean Recognition Scores and t Value
for the Ear by Syllable Interaction

Syllable	PA	GA	KA	BA	DA	TA
Left Ear	2.76	2.88	3.92	4.00	3.25	2.88
Right Ear	3.96	5.04	6.96	5.21	3.25	6.54
t Value	2.02	4.39*	6.14*	2.44	0.00	7.41*

* $p < .001$

following in that order respectively. The da sound did not contribute to the laterality effect. These data are somewhat at variance with the data presented by Studdert-Kennedy and Shankweiler (1970) who found that the stop consonants b, g, p, k, d, and t produced the strongest degree of asymmetry in that order respectively. Rather, these data are more consistent with Gerber and Goldman's (1971) finding that the stop consonants t, p, g, k, d, and b produced the strongest amount of asymmetry in that order respectively.

The ear by syllable analysis also revealed a significant ear main effect ($F_{1,23}=56.70$, $p<.0001$). This main effect shows, as was expected, the right ear preference. Also found was a significant syllable main effect ($F_{5,115}=7.82$, $p<.0001$). This main effect is the result of Ss' superior performance for both the right and left ear of the ka sound and the inferior performance for both the right and left ear of the da sound. Mean recognition scores for this main effect are presented in Table 9. The summary table for the ear by syllable data is presented in Table 10.

The question concerning the effect of serial position was treated by an ear by serial position ANOVA. As before, the dependent measure was number of correctly identified sounds for both the left and right ear at each of the possible six positions. It will be recalled that the

TABLE 9

Mean Recognition Scores for the

Syllable Main Effect

Syllable	PA	GA	KA	BA	DA	TA
Score	3.46	3.96	5.44	4.60	3.25	4.71

TABLE 10

Analysis of Variance Summary Table for

the Two Factors Ears and Syllable

Source	df	Mean Square	F
Ear	1	245.68	56.70**
Error	23	4.33	
Syllable	5	33.18	7.82**
Error	115	4.24	
Ear x Syllable	5	22.51	7.65**
Error	115	2.94	
Total	264		

* $p < .001$

** $p < .0001$

probability of the correct foil occurring in any of the six positions was one-sixth.

The ear by serial position interaction was significant ($F_{5,115}$=2.83, p<.05). The reason for this interaction is the relatively constant performance of the right ear in sound recognition for serial positions three and four while the left ear shows a considerable drop in sound recognition for serial position four relative to serial position three. It must be noted that this interaction accounted for approximately 9% of the experimental error variance. Thus, it is not unreasonable to conclude that this significance is spurious.

Also found in this analysis was a significant ear main effect ($F_{1,23}$=56.07, p<.0001). This finding shows that the right ear was preferred to the left ear regardless of serial order. A significant serial order main effect was also obtained ($F_{5,115}$=7.32, p<.001). This main effect is the result of Ss' inferior performance in detecting the correct answer when it appeared in serial position five. Interpretation of this main effect is not straightforward and it is suggested that future researchers using tasks which employ serial order be sensitive to its possible effects. Mean recognition scores for this main effect are presented in Table 11. The summary table for the ear by serial order analysis is presented in Table 12.

TABLE 11

Mean Recognition Scores for the Serial Order Main Effect for Verbal Sounds

Position No.	1	2	3	4	5	6
Score	4.15	4.54	4.71	3.81	3.13	4.85

TABLE 12

Analysis of Variance Summary Table for the

Two Factors Ear and Serial Order for Verbal Sounds

Source	df	Mean Square	F
Ear	1	208.42	56.10***
Error	23	3.72	
Serial Order	5	20.27	7.32**
Error	115	2.77	
Ear x Serial Order	5	4.21	2.32*
Error	115	1.81	
Total	264		

* $p < .05$

** $p < .001$

*** $p < .0001$

APPENDIX E

Supplemental Analysis: Non-Language Sound Condition

Introduction

Supplemental analyses were performed on the data from the non-language sound condition to determine whether any of the six sounds were more efficiently recognized than the others. The data were also analyzed to determine whether there was a serial order effect.

Results and Discussion

To determine whether there were any differences in the recognition of the six sounds, the data were analyzed by a one way ANOVA. The dependent measure was number of correctly recognized stimulus sounds. Analyses of these data revealed a significant sound recognition effect ($F_{5,115}=3.66$, $p<.01$). Inspection of these data shows that sound five was recognized more efficiently than any of the other sounds. Statistically, however, this difference was only significant for sound three ($t_{24}=3.19$, $p<.01$). Mean recognition scores for this effect are presented in Table 13.

As with the verbal sound condition, the question as to whether there was a serial order effect in the non-language sound condition was treated by an ear by serial order ANOVA. The ear by serial order interaction was not significant, however there was a significant serial order main effect ($F_{5,115}=9.55$, $p<.0001$). These data show a decreasing

TABLE 13

Mean Recognition Scores for
the Sound Effect

Sound	1	2	3	4	5	6
Score	11.08	11.50	9.54	11.13	13.79	11.08

efficiency in correct sound recognition with the passage of time, i.e. subsequent foils. Position one is recognized significantly better than all other positions except position two, and position six is recognized significantly less efficiently than all other positions except position five. Mean recognition scores for this main effect are presented in Table 14.

The most apparent explanation for these data is that the non-language sounds are not very stably encoded into memory store. With the passage of time the traces decay and recognition becomes much more difficult. This interpretation is consistent with the one offered in the main body of this manuscript. The summary table for this ear by serial order analysis is presented in Table 15.

TABLE 14

Mean Recognition Scores for the Serial Order Main Effect for Non-Language Sounds

Position No.	1	2	3	4	5	6
Score	6.58	6.08	5.58	5.67	5.52	4.67

TABLE 15

Analysis of Variance Summary Table for the
Two Factors Ear and Serial Order
for Non-Language Sounds

Source	df	Mean Square	F
Ear	1	7.67	2.99
Error	23	2.58	
Serial Order	5	19.59	9.55*
Error	115	2.05	
Ear x Serial Order	5	1.39	.93
Error	115	1.49	
Total	264		

* $p < .0001$

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