FUNCTIONAL BRAIN ASYMMETRY AND MONAURAL STIMULATION

by

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Abstract

Forty-eight right-handed female college students were presented with diotic or monaural auditory stimuli in each of three different conditions. The dependent variable was key press reaction time (RT) to sound onset. The three stimulus conditions were; (a) a single 1000Hz tone (T), (b) one of three different tones 980, 1000, and 1020 Hz (CT), (c) one of six spoken CVC nonsense words (L). Subjects were assigned to one of two presentation groups, directed presentation (DP) in which Ss were told which ear was to be stimulated, and random presentation (RP) in which the ear of presentation was random and Ss had no foreknowledge. Within each presentation condition Ss were divided into two report groups, report (Rep) in which Ss were required to identify the stimulus in addition to key press to stimulus onset, and (N Rep) in which Ss did not identify the stimulus. Each S received 24 trials to the left, right, and to both ears. The DP group, when not required to report, showed no RT difference as a function of ear stimulated in any of the three stimulus conditions. When required to report, diotic RTs were significantly faster than monaural RTs in the T sound condition. Both Rep and N Rep Ss using their right hand in the RP group showed right ear RTs significantly faster than those for the left ear in the T and L sound conditions. Stimulus report attenuated RTs only for the DP group. Subjects who could selectively attend, i.e., determine for themselves to which ear they would listen, had faster RTs than DP <u>S</u>s. These data show that stimulus competition is not a necessary condition for the demonstration of auditory asymmetry. A perceptual model is proposed which states that auditory asymmetry under either dichotic or monaural conditions is a function of selective attention. In the absence of specific instructions attention to one ear or the other may be determined by the nature of the stimulation. Assuming that contralateral auditory afferent pathways are more efficient than the ipsilateral pathways, superior right ear RTs imply that perception is occurring in the left hemisphere. Right ear superiority for both language sounds as well as non-language sounds supports the concept of a single active hemisphere in auditory perception.

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Introduction

Dichotic Listening: Storage and Asymmetry

This first chapter provides a review of the dichotic listening literature. Dichotic listening is considered as a technique for studying auditory memory and as a procedure for studying auditory functional brain asymmetry. Emphasis will be placed on the latter and on a review of the conditions under which asymmetry exists. The development of the hypotheses includes a discussion of the literature covering auditory asymmetry under monaural conditions. Prior to the statement of the hypotheses an attention model is suggested to explain monaural auditory asymmetry.

Broadbent's storage model. The term dichotic stimulation refers to the simultaneous presentation of two different sounds to the left and right ear. Broadbent (1954) noticed that when subjects were presented dichotically with a series of digits, three to each ear at a rate of one pair per half second, they tended to respond by reporting first all the digits presented to one ear followed by the digits presented to the other. This phenomenon is referred to as ear order report (EOR). When the interval was increased to one second the subject was able to respond in the temporal order of digit presentation. However, when the digits were presented with rapid alternation between the ears the EOR was not noted. Broadbent (1954) concluded that dichotic memory is more difficult than monaural memory and suggested that this may be due to perceptual confusion rather than an actual failure of memory. In further research into the EOR phenomenon, Broadbent (1956) also concluded that the loss of efficiency in the dichotic approach is not in the storage but rather in the reception of information at the ears. Information enters simultaneously at the level of the ears but is verbally responded to successively. Such a process implies a storage or delay system.

These findings led Broadbent (1958) to formulate his storage deficit model to account for the EOR phenomenon. He suggested that under rapid rates of dichotic presentation, such as two pairs of digits per second, subjects will adopt the EOR since it appeared to be the most efficient strategy when subjects could not alternate attention between inputs. Under slower rates, such as one pair per second, the temporal report strategy will be employed. In the EOR condition subjects will process all the information at one ear. This Broadbent called the p-system. Information heard at the other ear is shunted into a short term store (the s-system) by a filter mechanism. After information in the p-system is processed, information in the s-system is retrieved. The s-system is used anytime the p-system is already full. Because of rapid decay in short term memory it is common to find more errors in the delayed s-system than in the p-system (Inglis, 1960; Treisman, 1960). If, on the other hand, the s-system was not being used Broadbent's storage model should predict associative symmetry for dichotic pairs. Murdock (1965), using dichotic pairs separated by 2.75 seconds, found that the accuracy of recall was equally good in either direction, i.e., left-right or right-left. Murdock interpreted these data to support associative symmetry.

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

<u>Functional brain asymmetry: a perceptual model</u>. The dichotic listening task has been widely used as a technique for studying memory and attention. It has also been quite useful in studying functional brain asymmetry. Kimura (1961a) noted that recognition of digits in the ear contralateral to the site of temporal lobectomy is more impaired following left temporal lobe removal than following the removal of right temporal lobe. Before surgery, subjects reported more digits from the right ear than from the left regardless of the site of a lesion. Normal subjects also showed this right ear superiority (Kimura, 1961b). Kimura states that for most people the left hemisphere is dominant for speech and that the contralateral ear is superior. By injecting sodium amytal into the internal carotid artery on one side, it is possible to temporarily disrupt the functions of that hemisphere (Wada & Rasmussen, 1960). Using this technique, Kimura (1961b) was able to locate the dominant hemisphere for speech and concluded that when speech is represented in the left hemisphere the right ear is preferred and that the left ear is preferred when the right hemisphere is speech dominant. Kimura argued that her findings of a right ear superiority are independent of handedness. Furthermore, since both the ipsilateral and contralateral pathways from the ear are very efficient (in normal subjects) the asymmetry will only be

noted in brain damaged cases or in a competition situation such as provided by the dichotic listening task.

The model developed by Kimura is a perceptual model. It holds that under dichotic listening conditions there is an enhanced perception for the ear contralateral to the speech hemisphere which, in most subjects, is the left hemisphere. This perceptual model is based on perceptual inequalities. Inglis (1962) suggested an alternative which is consistent with Broadbent's (1958) theory. This model emphasized storage rather than perception.

The role of the left hemisphere in the perception of speech is well documented in the literature (Meyer & Yates, 1955; and Milner, 1958) and such findings are being continuously supported through use of the sodium amytal technique. Milner, Taylor, and Sperry (1968), in arguing for the superior role of the left hemisphere for speech sounds, studied a group of patients who had undergone complete commissural section. Such patients are able to respond only to speech information that reaches 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 presentation of digits there was near complete suppression by the left hemisphere of inputs from the left ear. They were able to respond to left ear inputs, however, under a monaural condition indicating that the ipsilateral pathway can be utilized but not under the dichotic condition. Thus, further evidence is gained for the notion of a dominant speech hemisphere as well as dominant contralateral pathways.

In examination of 100 human brains, Geschwind and Livitsky (1968) found that in 65% of the cases the planum temporale behind Heschl's gyrus was larger on the left side, in 11% of the cases it was larger on the right side, and equal in 24% of the cases. Geschwind and Livitsky note that this finding is consistent with the finding that the left Sylvian fissure is longer than the right. This finding is consistent with a model based on perceptual inequality since Heschl's gyrus contains the primary auditory cortex while the planum temporale contains the auditory association area which constitutes Wernickes area.

Kimura's (1961a) argument that contralateral pathways are in some way more efficient than the ipsilateral pathways is well grounded in animal studies. Rosenzweig (1951) in his studies with cats stated that the auditory system is arranged so that each ear has neural connections with each hemisphere. However, more neural units are stimulated by contralateral stimulation. Because there was no detectable difference in latency or duration, the asymmetry that existed under dichotic stimulation must be due to the greater number of contralateral impulses which stimulated the dominant hemisphere. At some point within the auditory transmission system the contralateral and ipsilateral neural pathways overlap and at this point the more powerful contralateral pathways occlude the ipsilateral thus achieving greater cortical representation. Kimura (1967 & 1968) argues that this occlusion situation is ideally demonstrated in the dichotic listening task and it reaffirms her assertion (Kimura, 1963a) that a competition situation such as provided by the dichotic listening task is essential to demonstrate ear asymmetry.

Sparks, Goodglass, and Nickel (1970) used real words and digits in a dichotic listening test. Subjects were either left brain damaged or right brain damaged. These authors noted that Kimura's (1961a, 1961b) explanation could not account for impaired speech perception when the injury was in the right hemisphere. They suggested that the competition between the contralateral and ipsilateral pathways is sufficient to explain the effects of a left brain lesion. However, to explain the deficit in speech perception as a result of a right brain lesion, the perceptual model would have to be expanded to include the non-language (opposite) 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 report occurs within the dominant left hemisphere. This competition is between the contralateral pathway from the right ear which takes a direct route to the left hemisphere and the contralateral pathway from the left ear which takes a direct route to the right hemisphere and then must follow the transcallosal pathway to the left hemisphere.

Both right and left brain injured subjects in the Sparks et al. study showed an impaired performance on both words and digits in the ear contralateral to the site of the lesion. However, subjects with a left brain lesion also showed an impaired performance for the ear ipsilateral to the site of the lesion but to a lesser extent. The authors suggested that contralateral inputs connect with the primary sensory areas while callosal fibers connect the association areas. Following this extension of the perceptual model, a lesion in the right hemisphere will impair performance from the left ear but the dominant right ear in speech perception will be unaffected. A lesion in the left hemisphere will impair the contralateral right ear if the primary sensory area or the association area is affected. If the transcallosal pathway is also affected by the lesion, the ipsilateral ear is impaired. Thus only a left hemisphere lesion can impair both contralateral and ipsilateral inputs in the perception of speech sounds.

Conditions Producing Asymmetry

In the first two sections of this paper the dichotic listening technique has been explained as a means for studying memory and attention and functional brain asymmetry. In these next sections an examination will be made of the conditions under which asymmetry appears. Discussion will be provided of stimulus materials used, strategies of subjects in dichotic listening situations and respective researcher's interpretations of their findings. In many cases, it will be noted that researchers adhere to one of the two models described above (storage or perceptual) while others provide interpretations which build on one of the two models. In general, it will be concluded that the bulk of the evidence from studies of functional brain asymmetry are best explained by the perceptual model or a modification of that model.

Right ear superiority. In the experiments reported above by Kimura (1961a, 1961b, 1963a), subjects were permitted free recall, i.e., they could recall the digits in any way they preferred. Bryden (1963) confirmed the finding that subjects identified digits presented to the right ear more accurately than those presented to the left and he further noticed that subjects preferred the EOR, with the right ear reported first. To evaluate the effects of order of report, he also instructed subjects to report each ear equally often. Under this condition the right ear superiority still held. Bryden interpreted his findings as due to a true perceptual difference specific to verbal material. Bryden's (1963) active support for the perceptual model was questioned in a subsequent paper (Bryden, 1964). In this article he reported three experiments and noted that subjects used the same strategies for real words as they do for digits, that verbal associations between elements in the series can influence the recall strategy, and finally that the use of the same digit on both channels can lead to shifts between ears. This study supported two aspects of Broadbent's (1958) theory; that of rapid decay in short term memory and that switching between ears requires time. While Bryden concluded that switching is a more efficient strategy, he suggested that Broadbent's time estimation of switching needed to be modified. At a later time Bryden (1967) actively refuted Inglis' (1962) suggestion that ear order effects were due to memory deficits rather than perceptual deficits.

Dirks (1964) used real words, filtered words, and digits in both a monaural and dichotic test. Under the monaural conditions there were no significant differences between the two ears. However, under the dichotic condition, the right ear was superior for all three types of words. Like Kimura, Dirks concluded that competition between contralateral and ipsilateral pathways was necessary to demonstrate ear asymmetry.

Bartz, Satz, Fennell, and Lally (1967) presented subjects 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 conditions subjects reported by the EOR rather than in temporal sequence even though meaningful associations did exist. As in previous studies, the right ear was superior and Bartz, et al., adopted the perceptual model.

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 (Borkowski, Spreen & Stutz, 1965). These authors noted that while the right ear is most often preferred as the immediate recall channel, it is also more efficient when used as the storage channel in situations where subjects are asked to recall from the left channel first. This finding, that the right channel is more efficient as the storage channel, was supported by the above mentioned Bartz, et al. study.

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) among the same subjects. Total recall of both ears was superior for the function words with the nonsense words being recalled less efficiently. While all three types of words demonstrated right ear asymmetry, the authors noted that the words most easily recalled (function words) produced the smallest amount of asymmetry. Gerber and Goldman (1971) used synthetic nonsense speech sounds and compared three different recall conditions: free recall, ordered recall (subject instructed which ear to report), and ordered after recall (subject was instructed which ear to report after presentation of the stimuli). As with the above findings, Gerber and Goldman noted a right ear superiority with all three report conditions. They also confirmed Borkowski, et al. (1965), and the Bartz, et al. (1967) finding that the right ear is superior when used as the delayed channel. The right ear superiority for nonsense words has also been confirmed by Shankweiler and Studdert-Kennedy (1967), Kimura (1967), Spellacy and Blumstein (1970a and 1970b), and Studdert-Kennedy and Shankweiler (1970). Consistent with the finding of right ear superiority for nonsense words is Kimura and Folb's (1968) finding of a right ear superiority for backwards speech sounds.

In an attempt to determine under what conditions brain asymmetry exists during dichotic listening, Kimura (1963b) attempted to explore the development of asymmetry by testing children. Both boys and girls ages four and five demonstrated a right ear superiority. In a replication of this study, with a disadvantaged socioeconomic group, Kimura (1967) noted that boys lagged behind girls in the development of speech asymmetry, however, this lag disappears at an early age. Kimura attributed this finding to the normal developmental lag of boys and concluded that the left hemisphere is prepotent for speech at a very early age. Bakker (1967) noted that, using digits, the right ear is preferred to the left at the age of six but this advantage changes to the left ear until approximately the age of ten at which time the right ear regains superiority. Bakker (1968, 1969, and 1970) has also demonstrated a right ear preference for speech material by children.

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 superiority and noted that concrete words were more efficiently recalled by both ears. The authors concluded that ear preference does not vary as a function of mental age or chronological age. Like Kimura and Dirks (1964), they also stressed the necessity of having competition to demonstrate asymmetry.

Right ear superiority has been demonstrated for digits, real words, filtered words, nonsense words, synthetically produced speech sounds, and backwards speech under a wide range of conditions with many different types of subjects. It seems reasonable to conclude that this right ear superiority for these language sounds is due to the increased efficiency of the contralateral neural pathways and the role of the left hemisphere in processing language material. Language is defined as this range of speech sounds.

Left ear superiority. Milner (1962) noted that removal of the right temporal lobe seriously depressed scores on the Timbre and Tonal Memory subtests of the Seashore Measures of Musical Talents. Kimura (1964) hypothesized that if damage to the left temporal lobe impaired language recall and damage to the right temporal lobe impaired tone performance, then normal subjects should demonstrate a left ear preference for melodies. In a dichotic listening test composed both of digits and melodies administered to the same subjects, Kimura (1964) found a right ear superiority for digits and a left ear superiority for music. Kimura states that the differences between 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 superiority. She further argued (Kimura, 1967) that even familiar melodic patterns are best recalled by the left ear, therefore, familiarity is not a critical factor in this hemispheric specialization. Rather, she suggested 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 this finding 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, and 1968) offered the same evidence for the observed right hemispheric specialization for music as she does for left hemispheric specialization for speech, namely perceptual inequality; the superior contralateral pathways occlude the ipsilateral pathways to the music dominant hemisphere (which is most often the right hemisphere).

Treisman and Geffen (1967), in their studies on selective attention, suggested that when subjects were to shadow (repeat) the passage on one channel (primary response) and tap to key words on the same or opposite channel (secondary response) there was a perceptual limit with a filter selecting the two messages before they were fully analyzed. Subjects under this condition were less likely to identify the secondary target words than the primary ones. However, when a tone was used as the secondary response, as in the experiment reported by Lawson and discussed by Treisman and Geffen, the difference between the primary and secondary stimuli disappeared. Treisman and Geffen concluded that the analysis of simple physical signals precedes both the selective filter and the analysis of verbal content. This present interpretation of Treisman and Geffen's selective filter does not seem at variance with Kimura's concept of articulability. Both are concerned with the physical characteristics of the sound and advocate a perceptual model.

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

Spellacy (1970), using the dichotic technique, attempted to isolate components of music which might contribute to the left ear superiority. In addition to music; temporal patterns, frequency patterns, and timbre were used as the dichotic stimuli. Subjects were tested by means of recognition after five seconds or after twelve seconds. While the frequency patterns, temporal patterns and timbre stimuli failed to gain significance, the music stimuli were highly significant. Of more interest 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 superiority 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 fits 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 superiority for music they noted that recognition scores for musical stimuli were significantly higher than for tonal patterns. The authors confirmed Spellacy's (1970) finding that the size of the difference between ears for music and tone patterns decreased with an increase in length of the time interval and accepted the perceptual model. No significant differences between the two intensities were found.

In the above studies using tones, buzzer produced sounds, and music, a left ear superiority has been found. These sounds will be defined as non-language. Following the perceptual asymmetry model, one could argue that this non-language material is most efficiently processed in the right hemisphere by most subjects and the contralateral ear is superior for recognition or recall.

A simple hemispheric distinction? Some new findings. From the above discussion on right and left ear superiority, it would appear that the functions of the two hemispheres of the brain in auditory perception were straightforward: the left hemisphere being superior for language material and the right hemisphere being superior for non-language material.

(Language and non-language being defined in terms of the above findings.) Recent studies, however, have questioned this distinction.

Shankweiler and Studdert-Kennedy (1967) used the dichotic listening technique to determine whether all features of phonetic elements were processed in the same way. They also examined at what stage in processing of speech, hemispheric differences in function became evident. The stimuli consisted of synthetic consonant-vowel (CV) syllables and synthetic steady state vowels in isolation. Shankweiler and Studdert-Kennedy found a significant right ear advantage for CV sounds but not for vowels. The authors concluded that laterality effects occur in dichotic presentation of nonsense syllables displaying phonemic contrasts which implies that the speech dominance of the left hemisphere is in speech perception at the level of speech sound and structure. Furthermore, since the laterality effect was greater in CV pairs differing on two articulatory features than pairs differing on one, this implies that perception of CV syllables may involve a process of analysis by feature. The left ear performance on vowels, they suggested, is midpoint between music recognition and speech recognition.

Such findings are consistent with Kimura's (1967) suggestion that articulability is the critical feature, but implies that all speech sounds are not equally weighted.

Studdert-Kennedy and Shankweiler (1970) examined this concept in more detail by analyzing the components of the speech signal. In this study the dichotic stimuli were natural consonant-vowel-consonant (CVC) syllables. Right ear superiority was found for initial and final stop consonants and, as in their previous study (Shankweiler and Studdert-Kennedy, 1967), the vowels failed to achieve significance. The articulatory features of voicing and place produced a right ear superiority, however, the authors suggest 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 Kimura's (1961b), stating that right ear superiority is the result of stronger contralateral pathways while the left ear input must follow a less direct path to dominant hemisphere. They 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 language hemisphere is specialized. 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. The value of speech material is not its acoustic structure, rather it is the phonological information that the acoustic structure conveys to the language hemisphere. The failure, then, of vowels to achieve significant right ear superiority may be explained in terms of the loss of phonological information they conveyed and it was for this reason that they failed to show a right ear preference. The stimulus material used by Gerber and Goldman's (1971) study was the same as that employed by Shankweiler and Studdert-Kennedy (1967). Gerber and Goldman found that consonant pairs which differed on only one articulatory feature, either voicing or place, were most easily identified. These findings supported those found by Shankweiler and Studdert-Kennedy (1967).

That there may be qualitative differences within language stimuli was also suggested by Spreen and Boucher (1970). Noting that speech is dependent on the frequency characteristics of the signal, they hypothesized that if the higher frequencies were filtered out of words the consonants of the speech message 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 superiority. Spreen and Boucher interpreted their findings as consistent with Shankweiler and Studdert-Kennedy and suggested that the right ear superiority is a language related phenomemon which disappears as the sounds become more dissimilar from normal speech. Kirstein (1970) stated 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-speech processes in the right hemisphere.

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

Considering their findings, Spellacy and Blumstein (1970a, 1970b) suggested that the notion of a simple hemisphere 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 yielded left ear superiority for vowels then it was reasonable to assume that the same should be true for consonants which, unfortunately, was not the case. The second problem for a bilateral model was found in the fact that the left ear performance for vowels was the same in both the language and the non-language groups. The switch from right to left ear superiority in the non-language condition does not arise from an increased efficiency of the left ear but rather from decreased performance of the right ear.

Darwin (1969), in using dichotic presentation of fricatives, noted that subjects perform equally well with either ear and suggested that speech sounds only give a right ear advantage when they contain certain formant transitions. Following this notion, Spellacy and Blumstein (1970a) suggested that it may be the frequencies which are associated with the transition from consonants to vowels which give rise to the right ear superiority. When vowels are attended to as language this transition enhances perception, however, when not attended to as language the transition inhibits perception. These writers further suggested that their data required an explanation which accounts for a selective attention phenomenon which can affect 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 stimuli are not attended to as language sounds the ability to detect such critical frequencies is decreased. Therefore, the left ear superiority demonstrated for certain non-language sounds may be explained in terms of a decrease in left hemisphere perception rather than right hemisphere superiority.

Spellacy and Blumstein (1970b) rejected the notion of bilateral hemisphere specialization in auditory perception and suggested 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 left or right ear superiority. The notion that frequency transitions are the critical characteristic in right ear superiority vor verbal sounds was further supported by Spreen and Boucher's (1970) study. Perhaps one of the most interesting implications from these studies by Spellacy and Blumstein concerns the concept of a single active hemisphere.

A language - non-language distinction is maintained but this distinction does not imply the involvement of the left or right hemisphere. Rather, it implies the degree of involvement of the single dominant hemisphere.

Auditory asymmetry and handedness. In this section, handedness will be discussed only so far as it concerns the studies cited and, more importantly, as it pertains to the development of the hypothesis in the following sections.

In discussing her brain damaged subjects, Kimura (1961b, 1963a, 1967, and 1968) has noted that right handed patients showed a language deficit when the lesion was in the left hemisphere and 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 argued that the ear opposite the dominant language hemisphere is more efficient, independent of handedness.

The independence of handedness, however, 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 the speech representation in the brain is not usually 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. Normal right handed subjects appear to be a relatively homogeneous population. From their sample, Branch, Milner and Rasmussen (1964) estimated, through the use of the sodium amytal technique, that ninety per cent of all right handers have speech represented in the left hemisphere. It is for this reason that most studies have used right handed subjects. Many researchers screen their subjects with questionnaires attempting to establish the degree of "right handedness".

The left handed population, on the other hand, appears much more heterogeneous. Branch, et al., (1964) estimated that only sixty per cent of the left handed subjects have speech represented in the left hamisphere. Curry and Rutherford (1967) included a group of left handed subjects in their study and noted that there is less asymmetry for the left handed group in processing speech material. They suggested that left handed subjects may have a greater equipotentiality for language function than right handers. Satz, Achenbach, Pattishall, and Fennell (1965), using digits in a dichotic listening test, compared left and right handed subjects. They found that the degree of asymmetry was greater for right handed subjects than for left handed subjects. Furthermore, the smaller ear asymmetry for left handed subjects was independent of the preferred ear. Satz, et al., suggested that this smaller asymmetry in left handed subjects may reflect a lack of a fully developed or specialized speech hemisphere in those subjects. Satz, Achenbach, and Fennell (1967) compared left and right handed subjects on a dichotic listening test and on three measures of manual performance. The dichotic listening test used digits and the three measures of manual performance were strength of grip, speed of tapping, and dexterity. Self-classified left handed subjects demonstrated variable lateral preference on both the manual and auditory tests. Self-classified right handed subjects 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 subjects on the basis of their composite manual performance scores. Three test-classified groups were found: strongly right handed, which comprised 17 per cent of the left handed group; ambidextrous (22 per cent); and strongly left handed (61 per cent). The first two groups demonstrated a right ear superiority for speech while the final group demonstrated a left ear superiority. Since self-classified left handed subjects 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.

Hécaen and Sauquet (1970), in studying right and left hemisphere syndromes in left and right handed subjects, noticed that the comparison between left and right hemisphere syndromes in left handed subjects displays less difference between frequencies of symptoms than the same comparison in right handed subjects. While their findings indicated that there appears to be a cerebral ambilaterality in left handed subjects, they also indicated that left handed subjects 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 subjects, however, these distrubances were seldom present with lesions to the right hemisphere. Thus, they concluded that the cerebral ambilaterality, as hinted at by Curry and Rutherford, occurs only with familial left handed subjects.

Development of the Hypotheses

The purpose of the preceding discussion has been to develop the two models used to account for ear asymmetry, provide a brief review of the literature in ear asymmetry, present some new findings, relate handedness to auditory asymmetry and, most importantly, to provide the concepts necessary for the development of the hypotheses presented at the end of this section. In these next two sections, material that is directly related to the development of the hypotheses will be explored.

Monaural vs. dichotic stimulation. Both the storage model and the perceptual model imply that dichotic stimulation is necessary in the demonstration of ear asymmetry. Kimura (1963a, 1964, 1967, and 1968) holds that competition between the contralateral and ipsilateral neural pathways is necessary for asymmetry to be demonstrated. Kimura (1964) suggested that the dichotic situation puts more demands on the system than the monaural does. Dirks (1964) and Jones and Spreen (1967) also argued that sounds must be competing. Studdert-Kennedy and Shankweiler (1970) feel that there are two necessary conditions to produce an ear advantage in dichotic listening; first, some part of the perceptual process must depend upon unilateral machinery; 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 advantage is noticed, they argue that these conditions must have been fulfilled.

In most studies cited above, dichotic stimuli have been used. The emphasis on competition is understandable since most attempts with monaural stimulation have failed to produce asymmetry. In a few studies auditory asymmetry has been demonstrated with monaural stimulation.

One of the first stidues was provided by Simon (1967) who used a 1000 Hz tone as the stimulus and reaction time (RT) as the response. Both left and right handed subjects were used in this study. Subjects were stimulated randomly at the left, right, or both ears. RT was significantly faster for the right than for the left ear. It was also noted that diotic trials were significantly faster than monaural trials. In a separate experiment reported in the same study, however, Simon noted that when subjects were told in advance as to which ear was to be stimulated, the right ear superiority was lost 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 stated that when the subject is uncertain as to which ear will be stimulated he tunes in his right ear thus yielding faster right ear times. In the case of diotic trials the expectancy explanation holds that the subject would be listening with one ear or the other hence would always be correct where he would not be correctly listening for some monaural trials. If the uncertainty is removed, as through instructions, then right ear superiority and diotic superiority should disappear. This expectancy model neatly fits the data.

Simon's findings are of particular interest for two reasons. First, auditory asymmetry was demonstrated under a monaural test condition and second, a right ear superiority was demonstrated for a stimulus material that should elicit a left ear preference if the original language - non-language continuum is followed. This second issue is most important and will be discussed later.

Bakker (1967) also found asymmetry under monaural conditions. Both verbal material (digit series composed of four, five or six digits) and non-language material (Morse code sound pattern of dots and dashes generated by a buzzer) were used on children ages six to twelve. The verbal stimuli were to be repeated while the non-language material was to be reproduced with the aid of a buzzer. The non-language material was retained significantly better with the left ear than with the right. The verbal material, while in the hypothesized direction, i.e., right ear superiority, 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 procedures as before (Bakker, 1967), tested boys ages 9 - 13 with learning disabilities. Non-language stimuli were retained better when presented to the left ear than when presented to the right. Digits were once again in the hypothesized direction but not significant. Bakker stated that the stimulus competition situation, as described by Kimura, may be one of the factors contributing to asymmetry but that it is not so much the manner of presentation (i.e., monaural or dichotic) as it is the kind of task that is vital in the demonstration of asymmetry. In this study, as well as the previous Bakker study, correct order was demanded before a response was considered correct.

To test the above notion (Bakker, 1968) that it was the kind of task as opposed to the manner of presentation, Bakker (1969) compared three methods of recall with monaural verbal stimulation. The verbal material in this test consisted of series of four and five letters presented to ten year old children. The three recall methods were: free recall (FR) in which the subject had to produce all the letters but in any order he preferred; serial recall (SR) in which all the letters had to be produced in order of presentation and; ordered recall (OR) in which the subject was told one letter of the series and then had to report its exact location in the series. Bakker found that in all conditions the four letter series were retained better than the five letter series. The SR and OR conditions revealed a right ear superiority whereas the FR condition did not.

Bakker (1968, 1969) argued that asymmetry is dependent on the nature of the task, and the requirement of ordered recall and list length are important factors. Bakker further suggested that another factor contributing to the asymmetry 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.

Using children age seven to thirteen, Bakker (1970) used both verbal and non-language stimuli. The verbal material was series of four, five, and six digits while the non-language material was buzzer produced dots and dashes series three, four, or five elements long. The medium length non-language series (four) produced the greatest amount of left ear dominance and the longest verbal series (six) produced the greatest amount of right ear dominance. Bakker also studied the relationship of eye dominance and lateral awareness to ear asymmetry. He found that right eyed children showed a right ear dominance for verbal material; children with normally developed lateral awareness showed a right ear dominance for verbal material and a left ear dominance for non-language material.

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 material be temporally reproduced. As a further explanation for the 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 pathways. When presentation is to the ipsilateral ear, greater distance must be travelled hence there is a greater loss. This suggestion is consistent with the above discussed bilateral perceptual model.

The fact that asymmetry occurs under both verbal and non-language conditions in this study 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) explained that verbal asymmetry was at its maximum under the longer series condition while for sound patterns it was at its maximum at medium length. Referring to studies of effects of right temporal lobe damage (see above), Bakker suggested that imitation of rhythmic patterns is temporally mediated by the right hemisphere while the left hemisphere can temporally mediate verbal material. Substances (digits, tones, etc.) are temporally mediated and the nature of the substances determine where its temporal order is cerebrally mediated.

As in the Simon (1967) study, Bakker's (1967, 1968, 1969, and 1970) findings are of particular import for the present study. Like Simon, Bakker demonstrated monaural asymmetry, however, his asymmetry is dependent on list length and temporal ordering. It is remembered that Simon's asymmetry did not depend upon such conditions as temporal order or length, however, his asymmetry was for the right ear with what appears to be non-language material. An attempted clarification of this discrepancy is, in part, the purpose of the present study.

Murphy and Venables (1970) also provided evidence for monaural asymmetry through the use of a signal detection task. Clicks with a varying interval between them were presented to one ear and the subject had to indicate whether he identified one or two clicks. Left ear performance was superior to that of right ear performance. When white noise was delivered to the ear opposite the clicks the left ear superiority was accentuated. Murphy and Venables interpreted their findings as consistent with Kimura's (1964) and Milner's (1962) that the left ear is superior for non-language material due to the predominant role of the right hemisphere.

Attention in Auditory Asymmetry

In the development of a perceptual model, Kimura (1963a, 1964, 1967 and 1968) has argued that auditory asymmetry may only be observed under dichotic listening conditions. Under rapid rates of presentation of dichotic stimuli (e.g., two pairs per second) perceptual asymmetry is defined as the superior recall for materials presented to the ear contralateral to the language dominant hemisphere. The storage model accounts for asymmetry under the same rapid rates of dichotic presentation as a result of decay of the material held in the s-system. In both models competing sounds are a necessary condition to produce asymmetry. However, the studies reported above by Simon (1967), Bakker (1967, 1968, 1969 and 1970), and Murphy and Venables (1970) have indicated that, while competition is a sufficient condition, it is not a necessary condition to produce asymmetry. A satisfactory explanation to account for this monaural asymmetry which is free from other cerebral functions such as temporal organization or concepts such as subject expectation has not been provided. An expectancy model may fit the data but conveys little information as to how the nervous system processes the stimuli in an asymmetrical manner. The current explanations offered for monaural asymmetry do not explain asymmetry under dichotic conditions and vice versa. This thesis expands the perceptual model to account for monaural asymmetry by incorporating the concept of attention. Such a model has the proposed advantage of explaining auditory asymmetry under both dichotic and monaural conditions.

Treisman (1969) defined attention as the selective aspect of perception and response and any theory about attention therefore presupposes a general knowledge about the nature of the perceptual system. Auditory stimuli are attended to at the level of the ears and are perceived at the level of the cerebral hemispheres. In the dichotic listening task, the subject's attention is distributed in some manner between his two ears. The observed asymmetries between the ears may then be explained by either superior contralateral pathways to the specialized cerebral hemisphere or as a result of unequal distribution of attention between the ears.

Treisman and Geffen (1968) and Treisman and Riley (1969) using dichotic words, argued that the right ear dominance represents a quantitative difference in the distribution of attention to the left and right ears. They recognize the role of the left hemisphere in language perception. If perception demands attention, then it would seem that auditory stimulus which puts greater demands on attention should produce a higher degree of asymmetry. Curry and Rutherford (1967) found that nonsense words presented dichotically produced a higher degree of asymmetry than real words, and suggested that this was because the recognition of nonsense words required the subjects to perceive each pheneme accurately whereas real words did not demand as much attention. Murray and Hitchcock (1969) directly studied the effect of attention in a dichotic listening test by imposing additional tasks. Subjects were randomly assigned to one of three conditions: not code, in which they were to mouth the word "the" after each dichotic pair; silent code, in which the subjects were to silently repeat to themselves all the digits on one channel only; and mouth code, in which the subjects were to verbally repeat all the digits on one channel only. Murray and Hitchcock found that the items that were verbally responded to were better recalled than those not verbally responded to. They further suggested that subvocal coding, such as the silent code attention condition, is not by itself enough to insure maximal recall.

The failure of previous researchers to show a right ear superiority for vowels led Spellacy and Blumstein (1970a) to suggest that since vowel sounds do not possess the critical frequencies of consonants they are not consistently attended to as language. By manipulating the subjects' attention with a language or non-language context, they demonstrated a right and left ear superiority respectively. These data offer direct support for the role of attention in auditory asymmetry. Subjects in dichotic listening tasks attend to simultaneous pairs of words, digits, musical passages, etc. as language or non-language. Asymmetry is the result of the subject's attention set.

The attention model may also be applied to tests of monaural asymmetry where the subject is responding only to the presence of tone such as in Simon's (1967) study. When subjects are told which ear(s) is to be stimulated they are able to focus their attention on that ear(s) and no asymmetry is observed. In such clearly defined situations, even when the stimulus is presented to the ear ipsilateral to the dominant hemisphere, any apparent differences between contralateral and ipsilateral pathways may be so slight that no differences are observed. This is consistent with Kimura's (1961b) suggestion that in normal subjects, under normal conditions, both pathways are extremely efficient. When monaural stimulation is presented in a random manner to the ears, the subject is unable to specifically focus his attention on any given ear. Rather his attention is distributed to both ears. Any observed asymmetry under this condition must therefore be due to increased attention at one ear or, in turn, the stimuli is more efficiently perceived by the dominant hemisphere via the superior contralateral neural pathways. Simon also found diotic trials to be faster than monaural trials. This is explained by the fact with attention divided, diotic stimulation always strikes the dominant ear whereas monaural trials hit the non-dominant ear at least half of the time.

Statement of the Hypotheses

Asymmetry under dichotic stimulation is well established in the literature. Asymmetry under monaural stimulation is not as well established. In either case, it is not clearly understood exactly why such asymmetries exist. In this study monaural stimuli will be used under conditions in which the subject's attention is manipulated. The attention model tested by this study holds that in situations in which the subject knows which ear(s) is to be stimulated there will be no differences between ear(s). When the subject does not know which ear(s) is to be stimulated the right ear will be more efficient than the left ear. Diotic stimulation should be more efficient than either right or left ear stimulation.

Extensive investigations of auditory asymmetry under conditions of monaural stimulation have been provided by Bakker (1967, 1968, 1969, and 1970). In his studies, the appearance of asymmetry was dependent on the length of the series and the requirement that the material be temporally ordered. The ability to temporally organize material according to Bakker was determined by the nature of the stimuli and was mediated by the respective dominant left or right hemisphere.

Following the attention model it would seem, however, that if there were a dominant hemisphere for a given type of auditory material and if the contralateral pathways were more efficient than the ipsilateral pathways that these additional mechanisms and tasks suggested by Bakker would not be necessary. Rather one should be able to demonstrate asymmetry monaurally with the mere presence of sound. This, in fact, has been done by Simon (1967). Subjects responded to the onset of tone by depressing a key giving a measure of reaction time (RT). When the subject's expectation was not fixed on a given input, right ear RTs were faster than the left and diotic RTs were faster than monaural. Since the subject is responding to the onset of the tone as opposed to any of its physical characteristics it should make no difference whether the sound was a tone as in Simon's study or any other sound, language or non-language.

The first sound condition in the proposed experiement will, in part, be a replication of Simon's study. Half of the subjects (Ss) will hear a tone presented randomly to the left, right or both ears. This will constitute the random presentation (RP) condition. The other half of the Ss will hear the tone in the left, right or both ears, however, they will be told ahead of time which ear(s) will be stimulated.

This will be the directed presentation (DP) condition. Response will be a measure of RT to the onset of the tone. As in the Simon study and following the attention model it is hypothesized that Ss will show a right ear superiority in the RP condition but not in the DP condition. Furthermore, it is hypothesized that diotic RTs in the RP condition will be faster than monaural RTs, but this superiority will not be present in the DP condition. Moray and O'Brien (1967) found that when Ss were asked to explicitly divide their attention between ears they performed at a much lower level than when they focused their attention on a single ear. Therefore it is also hypothesized that RTs from the RP condition will be slower than RTs from the DP condition.

The differences between left and right; monaural and diotic RTs, as hypothesized above and as found by Simon, should be accentuated if the difficulty of the task is increased. Increased difficulty under dichotic listening tests has increased asymmetry (Curry and Rutherford, 1967; Murray and Hitchcock, 1969). Treisman and Geffen (1967) found that when Ss were to shadow (repeat) a primary message in one ear and also tap to target words in either the primary or a secondary message that Ss correctly identified more target words in the primary message. Furthermore, detecting target words in the primary shadowed message had a less disruptive effect on shadowing than when targets were in the secondary non-shadowed message. It is also important to note that Ss in Treisman and Geffen's study were instructed as to which ear would receive the primary message.

To test this effect of increased task difficulty in this first tone stimulus condition (T) Ss in each presentation group will be assigned to one of two report conditions. Half of the Ss will be assigned to a no report (N Rep) condition in which they are only required to respond to the onset of tone as described above. The remaining half will be assigned to a report (Rep) condition. The Ss in the Rep condition will hear the same sound stimuli as those in the N Rep condition, however, they will be asked to evaluate each tone as being either the same as or different from the preceding tone after giving the measure of RT. All tones in this T condition will be of 50 milliseconds (msec.) and will be identical.

The Ss assigned to the RP condition who are required to report are hypothesized to show a greater degree of asymmetry than those in the N Rep condition. This will be expressed as a greater discrepancy between left and right ear RTs. No such differences are expected in the DP conditions. The overall effect of reporting in this T condition is expected to attenuate RTs in both the DP and RP condition.

The second sound stimulus condition in this study will use three different tones: high, medium, and low. The Ss will be randomly assigned to RP and DP conditions with the

Ss in each presentation condition being further assigned to a Rep or N Rep condition. All Ss in this complex tone (CT) stimulus condition will give a measure of RT while Ss in the Rep condition will also be required to attend to one of the physical characteristics of the stimulus, frequency. After giving the measure of RT these Rep Ss will be required to identify the sound as being of high, medium or low frequency.

To reduce the possibility that Ss do not respond first to the onset of sound and then return to identify its frequency, a tone of 50 msec. will be used. The 50 msec. tone permits enough time for frequency recognition. This procedure has the proposed advantage, in a monaural test for asymmetry, of not requiring temporal ordering by the Ss and is not dependent on the length of the series as suggested by Bakker (1967, 1968, 1969, 1970). In the DP condition, as in the Treisman and Geffen (1967) study, Ss will know which ear is to be stimulated. Consistent with the hypothesis in the T sound condition it hypothesized that there will be no significant difference in left and right ear RTs and monaural and diotic RTs. In the RP condition attention is divided. As above, it is hypothesized that the right ear RTs will be significantly faster than the left ear RTs and diotic RTs will be faster than monaural RTs. The effect of reporting is expected to accentuate the hypothesized asymmetries in the RP condition while no differences are expected in the DP condition. Since Ss in the Rep condition are required to perform some form of analysis on the stimuli as well as respond to their presence, the overall effect of reporting is expected to attenuate RTs in both presentation conditions.

The first two factors of this study have used tone as the stimulus and the hypothesized asymmetries have been in the direction of the left hemisphere. In the third condition, language material will be used. In this language condition (L), as in the T and CT conditions, half of the Ss will be required to identify each stimulus in one of the two presentation conditions. In the perception of phonemic material some further mechanism such as Spellacy and Blumstein's (1970a) frequency analysis or Studdert-Kennedy and Shankweiler's (1970) linguistic device is implied. This test should be much more sensitive if nonsense words are used, since recognition of nonsense words requires the S to perceive each phoneme accurately; a requirement which is not as strict for real words (Curry and Rutherford, 1967).

Under these conditions it is hypothesized, as with the above T and CT conditions, that RTs will be faster for the right ear than the left under the RP condition. Diotic RTs will be faster than monaural RTs. Such differences will not be present in the DP condition. However, since attention is divided in the RP condition and not in the DP condition of L it is hypothesized that DP RTs will be faster than RP RTs. The effect of reporting is expected to follow the same trend as hypothesized in the T and CT conditions.

In all of the sound, presentation, ear and report conditions Ss will respond with their left and right hands. Auditory information processed in the dominant hemisphere must cross the corpus callosum to effect a response with the non-dominant hand. In such a case the non-dominant left hand RTs should be slower than right hand RTs. However, since Ss are responding after perception it is hypothesized that no difference between hands will be present between presentation conditions. A general trend independent of presentation condition may favor right hand RTs.

The hypotheses to be tested in this study can be summarized as follows:

1. In all stimulus conditions (T, CT, L), right ear RTs will be faster than left ear RTs in the RP condition.

2. In all stimulus conditions, diotic RTs will be faster than monaural RTs in the RP condition.

3. In all stimulus conditions, no significant differences will be found between ears (left, right and both) in the DP condition.

4. In all stimulus conditions, the effect of reporting will increase the RT differences between the left and right ears in the RP condition. Right ear RTs will be faster than left RTs and these differences will exceed those in the N Rep condition.

5. In all stimulus conditions where Ss are to report,

diotic RTs will be faster than monaural RTs.

6. In all stimulus conditions, the effect of reporting will have no significant effect in the DP condition.

7. In all stimulus conditions, DP RTs are expected to be faster than RP RTs.

8. In all stimulus conditions, reporting Ss' RTs are expected to be slower than non-reporting Ss' RTs.

Methods

Subjects

The Ss were 48 right-handed female college students with a mean age of 18 years, 7 months (range 17 years, 0 months to 23 years, 6 months). The Ss 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 and Benton, 1967).

All Ss had normal hearing acuity as defined by the ability to detect a pure tone of 500, 750, 1000, 1500, and 2000 Hz delivered at 20 dbs (ISO, 1964). All Ss had adequate motor response as defined by an average reaction time on six trials of less than 300 msec. (mean, 205 msec.). These six trials were the practice trials for the first condition.

Experimental procedure and apparatus

All Ss were randomly assigned to one of two presentation conditions and to one of two report conditions. Within these conditions all Ss were tested under each of three levels of stimulus presentation: tone (T), complex tone (CT), and language (L). Each of these conditions are discussed separately.

Presentation. Twenty-four Ss were randomly assigned to a directed presentation (DP) condition in which they were instructed as to which ear(s) was to be stimulated. The other half were assigned to a random presentation (RP) condition in which they did not know which ear(s) was to be stimulated.

Report. Within each presentation condition, half of the Ss (12) were randomly assigned to a report (Rep) condition. Rep Ss were required to make some comparative comment on the nature of the stimulus (e.g., same or different) as well as give a measure of reaction time (RT). The remaining half of the Ss were assigned to a no report (N Rep) condition in which they were required only to give a measure of RT. The specific presentation and report instructions are discussed separately for each sound condition.

The Ss in each presentation and report condition heard the three sound stimulus conditions in one of the six possible orders: T, CT, L; T, L, CT; CT, T, L; CT, L, T; L, T, CT; and L, CT, T. Two Ss were randomly assigned to each of these orders. Within each of these orders the stimulus was delivered to the left (L), right (R), or both (B) ears.

All stimuli were pre-recorded on stereophonic recording tape and were presented to Ss by a Sony 650 tape recorder via Koss KO 27b head phones. The RP stimulus presentation was the same for all Ss in all three stimulus conditions while the DP stimulus material were appropriately counterbalanced within each of the three stimulus conditions with Ss being stimulated in the following manner: L, R, B; R, L, B; B, R, L; B, L, R; R, B, L; and L, B, R. Two Ss were randomly assigned to each ear order.

The dependent measure to all levels of sound presentation was a measure of RT. Stimulus onset on the tape triggered an audio gate which started a Hunter klockounter. The Ss pressed a key, stopping the clock giving a measure of RT. Within each counterbalanced condition there were twenty-four measures of RT from each ear (left, right, both). Half of the trials for each S were from the left hand and half were from the right hand. Half of the Ss in each presentation and report group responded first with their left hand then with their right hand. The other half responded first with their right hand. Half of the Ss heard the left channel at their left ear while the other half heard the left channel at their right ear.

In each of the sound conditions the stimuli were numbered consecutively to serve as a cue that a stimulus was to be delivered. The numbers were diotically, i.e., simultaneously, presented to both ears at approximately 65 db. Stimuli were randomly presented zero to three seconds after the presentation of the number. Anticipation was defined as a RT below 60 msec. Additional trials with counterbalancing maintained were provided for those Ss who anticipated a stimulus so that all Ss were scored on an equal number of trials. Since the stimulus tapes were pre-recorded, the time interval from the number to the stimulus presentation was the same for all Ss. There were approximately ten seconds between each number.

Tone condition (T). As in the study by Simon (1967), the tone was of 1000 Hz for all trials and was delivered at approximately 82 db (A). Intensity was measured by placing a sound level meter between the headphones and adjusting the volume accordingly. This procedure was performed for both the left and right phone. Tone duration was 50 msec. Instructions to Ss in the RP condition of T were as follows:

> "This is a test of auditory perception and reaction time. You will hear a tone in either your right ear, your left ear, or in both ears. The tone will be randomly presented to your ears so there is no way for you to know ahead of time which of your ears will hear the tone. As soon as you hear the tone press the key in front of you as fast as you can. Before each tone you will hear a number at both of your ears. This number is to prepare you for the tone. Please do not press the key until you hear the tone but when you do hear the tone press it as fast as you can because what we are most interested in is how fast your reaction times are."

The Ss in the DP condition of T received the same instructions except they were told exactly which ear(s) was to be stimulated. The Ss in the Rep condition of T received the same instructions except they were asked to compare each tone with the previous one and state whether it was the same as or different from the one they just heard. The Ss were given six practice trials; three with each hand, and two to the left ear, the right ear, and both ears.

Complex tone condition (CT). Three tones of 980, 1000, and 1020 Hz delivered at approximately 82 db were used. Tones were 50 msec. long. The task for all Ss was to give a measure of RT. The Ss in the Rep condition were also asked to identify the sound as being of high, medium, or low frequency. The three tones were recorded and randomly presented to the ears in the two presentation conditions. The Ss heard each frequency, in each ear condition, eight times. On half of these the right hand was used and on the other half the left hand was used. The instructions were similar to those in the T condition. The Ss had six practice trials; two of each frequency, three with each hand.

Language condition (L). The same experimental procedure used in the T and CT conditions was used in the L condition except that the stimuli were language. Shankweiler and Studdert-Kennedy (1967) and Studdert-Kennedy and Shankweiler (1970) failed to demonstrate a significant right ear superiority for vowels. Spellacy and Blumstein (1970a) demonstrated that vowels could be perceived as speech or non-speech but noted that consonants show a significant right ear superiority regardless of context situation. These latter authors suggested that the critical frequencies involved in the perception of sounds, as being verbal, are probably those associated with the transition from consonants to vowels. Therefore, to assure that the stimulus material in this L condition was truly language as opposed to the tone conditions, only consonant-vowel-consonant (CVC) nonsense syllables were used. Nonsense words were preferred to real words since their recognition depends on accurate perception of each phoneme to a greater extent than real words (Curry and Rutherford, 1967).

Studdert-Kennedy and Shankweiler (1970) found that the stop consonants b, g, p, k, d, and t produced the strongest degree of asymmetry in that order respectively. Gerber and Goldman (1971) found the same laterality effect for the stop consonants but in a slightly different order t, p, g, k, d, and b. Six CVC words were used. Each began with one of these stop consonants and ended with a different one. The six stimulus words were: bouk, gup, poge, keed, dote,[1] and tib. The words were recorded and randomly presented to the ears in the two presentation conditions. The Ss responded to each word two times, twice with each hand, under each ear condition. The Ss in the Rep conditions were required to repeat the word as well as give a measure of RT. Instructions were similar to those outlined above. Prior to the test Ss heard each word once and received six practice trials; two at each ear, three at each hand with different words.

Analysis of Data

Table I shows the experimental design used in this study. The RT hypotheses were tested by a two levels of

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[1] At the completion of this study it became apparent to this writer that the word 'dote' was not a nonsense word.

Table I

Experimental design for the five factors: presentation, report, sound, ears, and hands.

				TONE						COMPLEX TONE						LANGUAGE					
				ears						ears						ears					
				left		right		both		left		right		both		left		right		both	
				hand						hand						hand					
				L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
DIRECTED PRESENTATION	NO REPORT	SUBJECTS	1 Thru 12																		
	REPORT		13 Thru 24																		
RANDOM PRESENTATION	NO REPORT	SUBJECTS	25 Thru 36																		
	REPORT		37 Thru 48																		

presentation by two levels of report by three levels of sound by three levels of ears by two levels of hands design. There were repeated measures on the last three factors. A univariate analysis of variance (ANOVA) for repeated measures was used. Separate analyses were also performed for the left, right, and both hands in each of the sound conditions. All *t* tests were based on the mean square error term from the analysis of variance.

Results

Mean RTs were computed for the different sound conditions. RT is defined as a score between 60 and 600 msec. Analysis of variance (ANOVA) was performed on the following five factors: presentation, report, sound, ears and hands. This was a two between, three within design.

The ANOVA yielded significant main effects for report ($F_{1,44}=5.73$, $p<.05$); sound ($F_{2,88}=19.75$, $p<.001$); ears ($F_{2,88}=5.71$, $p<.01$); and hands ($F_{1,44}=6.37$, $p<.01$). The following interactions were significant: hands by report ($F_{1,44}=5.35$, $p<.05$); hands by sound ($F_{2,88}=5.04$, $p<.01$); sound by ears ($F_{4,176}=15.01$, $p<.001$); hands by sound by presentation ($F_{2,88}=3.57$, $p<.05$); and hands by sound by ears by presentation ($F_{4,176}=2.77$, $p<.05$). The summary table for this five factor ANOVA is presented in Table II.

The main hypotheses of this study were within each sound condition not between conditions. The data were analyzed separately for each of the three sound conditions. An analysis of variance was first performed on both hands then separately for the left and right hands. A total of ten analyses were performed.

Tone condition (T): both hands. The ANOVA for the four factors: presentation, report, ears and hands revealed no significant interactions. The summary table for this four factor ANOVA is presented in Table III. A significant ears main effect ($F_{2,88}=5.71$, $p<.01$) was found (see Figure 1).

Table II

ANOVA for factors: Presentation, Report, Sound, Ears & Hands

Source	df	Mean Square	F
Presentation	1	0.00292	0.05
Report	1	0.37064	5.73*
Presentation x Report	1	0.14130	2.18
Error	44	0.06468	
Sound	2	0.13102	19.75***
Sound x Presentation	2	0.00130	0.20
Sound x Report	2	0.04592	6.92**
Sound x Pres x Report	2	0.00111	0.17
Error	88	0.00663	
Ears	2	0.00355	5.88**
Ears x Presentation	2	0.00158	2.61
Ears x Report	2	0.00012	0.20
Ears x Presentation x Report	2	0.00075	1.25
Error	88	0.00060	
Hands	1	0.00503	6.37**
Hands x Presentation	1	0.00141	1.79
Hands x Report	1	0.00423	5.35*
Hands x Presentation x Report	1	0.00080	1.01
Error	44	0.00079	
Sound x Ears	4	0.00883	15.07***
Sound x Ears x Pres	4	0.00071	1.21
Sound x Ears x Report	4	0.00050	0.86
Sound x Ears x Pres x Report	4	0.00048	0.81
Error	176	0.00059	
Sound x Hands	2	0.00361	5.04**
Sound x Hands x Pres	2	0.00256	3.57*
Sound x Hands x Report	2	0.00208	2.90
Sound x Hands x Pres x Report	2	0.00127	1.77
Error	88	0.00072	
Ears x Hands	2	0.00026	1.23
Ears x Hands x Presentation	2	0.00017	0.79
Ears x Hands x Report	2	0.00003	0.12
Ears x Hands x Pres x Report	2	0.00064	3.01
Error	88	0.00021	
Sound x Ears x Hands	4	0.00021	1.09
Snd x Ears x Hands x Pres	4	0.00054	2.85*
Snd x Ears x Hands x Rep	4	0.00016	0.83
Snd x Ears x Hnds x Pres x Rep	4	0.00017	0.89
Error	176	0.00019	
Total	816		

* $p<.05$
** $p<.01$
*** $p<.001$

Table III

ANOVA for four factors: Presentation, Report, Ears and Hands for Ss in the Tone condition

Source	df	Mean Square	F
Presentation	1	0.00003	0.00
Report	1	0.04413	3.04
Presentation x Report	1	0.03969	2.73
Error	44	0.01451	
Ears	2	0.00083	5.71**
Ears x Presentation	2	0.00013	0.91
Ears x Report	2	0.00005	0.32
Ears x Presentation x Report	2	0.00014	0.98
Error	88	0.00015	
Hands	1	0.00009	0.20
Hands x Presentation	1	0.00066	1.46
Hands x Report	1	0.00096	2.13
Hands x Presentation x Report	1	0.00030	0.66
Error	44	0.00045	
Ears x Hands	2	0.00027	1.72
Ears x Hands x Presentation	2	0.00046	2.98
Ears x Hands x Report	2	0.00005	0.33
Ears x Hands x Pres x Rep	2	0.00032	2.06
Error	88	0.00015	
Total	240		

** $p < .01$

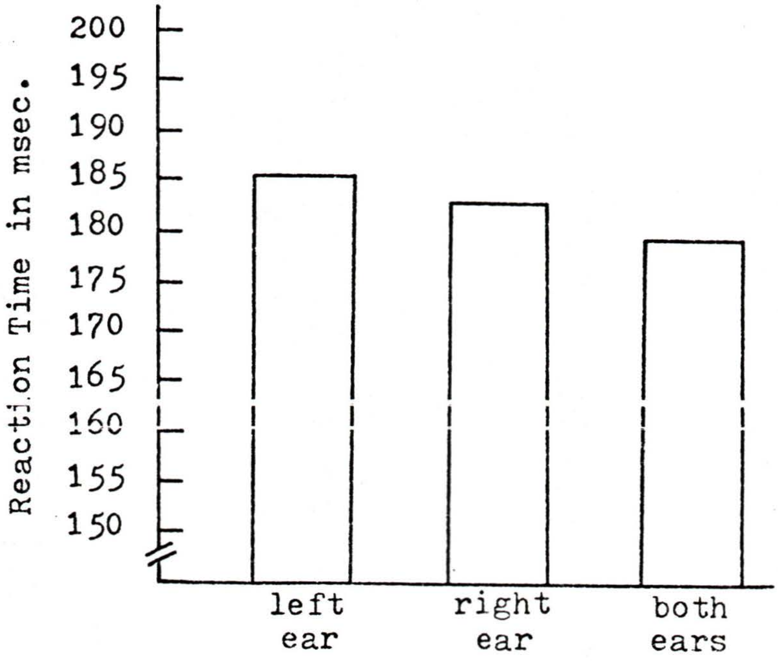

Figure 1. Left, right, and both ears reaction times for Ss in the Tone condition using their left and right hands.

Examination by a two tailed t test failed to reveal any significant difference between the left and right ears. Diotic RTs were significantly faster than left ear RTs but not those for the right.

Tone condition (T): right hand. The analysis for the three factors presentation, report, and ears produced a significant ears main effect ($F_{2,88}=6.33$, $p<.01$) and a significant presentation by report by ears interaction ($F_{2,88}=3.11$, $p<.05$). The summary table for this ANOVA is presented in Table IV. This interaction which is illustrated in Figure 2 was due to the superior right ear performance in the RP group and to the effect of reporting in the DP group. Table V gives the means and t values for this interaction. In the RP condition, right ear RTs were better than left ear RTs for both the Rep ($t_{44}=1.660$) and N Rep ($t_{44}=2.282$) conditions. In the RP N Rep condition, Ss were faster with diotic stimulation than with left or right ear stimulation. While in the hypothesized direction, this difference did not reach statistical significance. The RP Ss in the Rep condition did not show this trend. Diotic RTs were slower than right ear RTs and only slightly faster than left ear RTs. These differences did not achieve significance. The N Rep Ss showed no significant difference in RTs with the left, right and both ears. As hypothesized their RTs were faster than either N Rep or Rep RP Ss. The DP Ss in the Rep conditions also showed no significant

Table IV

ANOVA for the three factors: Presentation, Report and Ears for Ss using their right hand in the Tone condition

Source	df	Mean Square	F
Presentation	1	0.00047	0.06
Report	1	0.01604	2.06
Presentation x Report	1	0.01656	2.13
Error	44	0.00777	
Ears	2	0.00089	6.32**
Ears x Presentation	2	0.00035	2.47
Ears x Report	2	0.00000	0.01
Ears x Presentation x Report	2	0.00044	3.11*
Error	88	0.00014	
Total	120		

* $p < .05$

** $p < .01$

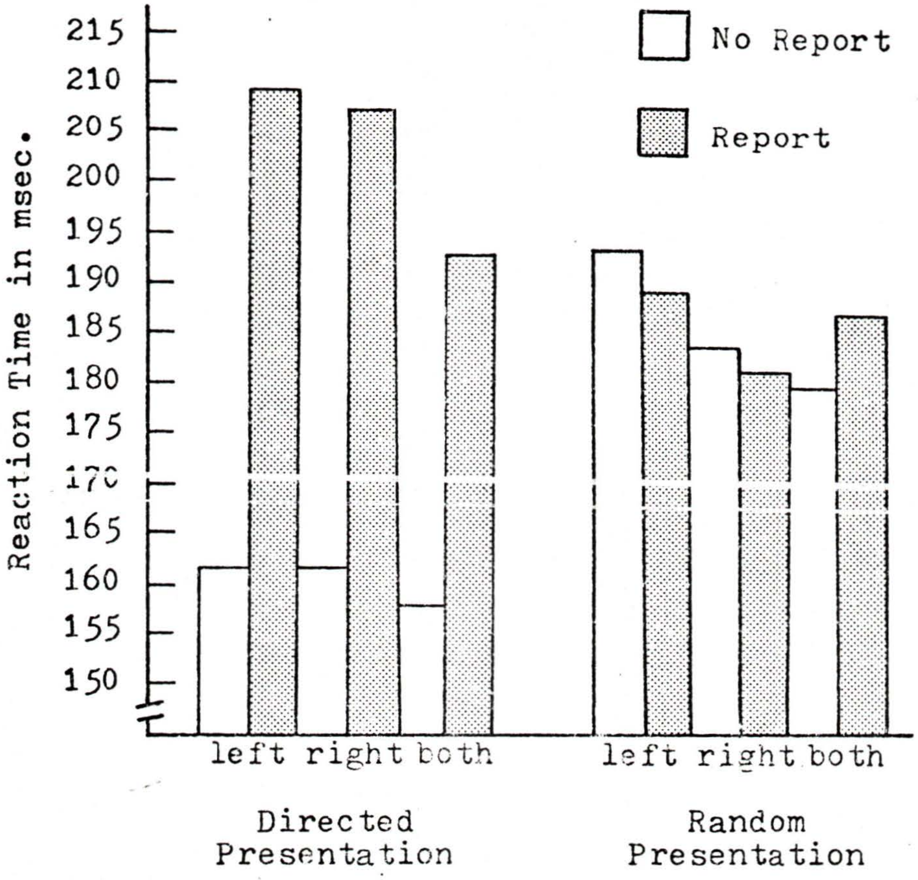

Figure 2. Presentation and Report reaction times for the left, right and both ears for Ss in the Tone condition using their right hands.

Table V

Means and _t_ values for the Presentation by Report by Ears
interaction for _S_s using their right hand
in the Tone condition

	No Rep			Rep		
	DP	RP	_t_	DP	RP	_t_
L ear	.161	.193	1.508	.208	.188	.943
R ear	.161	.182	.990	.206	.180	1.226
_t_	0	2.282**		.415	1.660□	
R ear	.161	.182	.990	.206	.180	1.226
B ears	.157	.179	1.037	.193	.186	1.223
_t_	.830	.622		2.698***	1.245	

	DP EARS			RP EARS		
	L	R	B	L	R	B
Rep	.208	.206	.193	.188	.180	.186
No Rep	.161	.161	.157	.193	.182	.179
_t_	2.216**	2.121**	1.697*	.236	.094	.330

* $p < .05$

** $p < .025$

*** $p < .005$

□ $p = .053$

differences between their left and right ears, however, diotic RTs were significantly faster than either the left or right ear RTs. The Ss required to report in the DP condition had slower RTs than RP Ss in either the Rep or N Rep conditions except for those Ss required to report in the RP condition. Directed presentation report Ss were significantly slower than DP N Rep Ss as determined by the appropriate t test.

Thus the hypothesis that right ear RTs would be significantly faster than left ear RTs in the RP condition was supported with the right hand in both the Rep and N Rep groups. Also the hypothesis that DP Ss would show no difference between the left and right ears was also supported by both the Rep and the N Rep groups. The hypothesis that the diotic RTs would be faster in the RP group was not supported by either the Rep or N Rep Ss. The Rep group showed a slight but non-significant trend in the opposite direction. The hypothesis that diotic RTs would not vary significantly in the DP Ss was supported with N Rep Ss while Rep Ss showed significantly faster diotic RTs than those for either the left or right ear. The hypothesis that reporting would increase ear asymmetry was not supported.

The hypothesis that DP Ss would be faster than RP Ss was not confirmed. The N Rep DP Ss were faster than the counterpart RP group, but DP Rep Ss were slower than RP Rep

Ss.[1]

Tone condition (T): left hand. Analysis of variance of the left hand RTs revealed only a main effect for the report condition ($F_{2,88}=4.04$, $p<.05$). This main effect (see Figure 3) supported the hypothesis that Rep Ss will have significantly slower RTs than N Rep Ss, however, this generalization only holds when the left hand is considered.

The ear RTs showed no consistent trend in the hypothesized direction in the RP condition. The summary table for this ANOVA is presented in Table VI.

Complex tone (CT). ANOVAs for the right, left and both hands respectively showed no significant main effects or interactions. (See Tables VII, VIII, and IX.) Examining the right hand, the presentation by report interaction was of interest even though it fell short of the usual level of significance ($F_{1,44}=3.58$, $p<.06$). This interaction, which is shown in Figure 4, was consistent with the findings in the T sound condition. Previously it was noted that Ss in the DP condition who were required to report had slower RTs than N Rep DP Ss or N Rep or Rep RP condition Ss. This trend was consistent in the CT condition though not significant. Of further interest was the trend favoring

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[1] The statistically significant three way interaction reported in this section falls slightly short of significance at the .05 level leaving only the significant ears main effect if a Geisser-Greenhouse conservative F test for repeated measures designs was adopted. However since the findings reported above are consistent with the asymmetry hypothesis and the previous findings of others, the traditional F test value was adopted (Kirk, 1968).

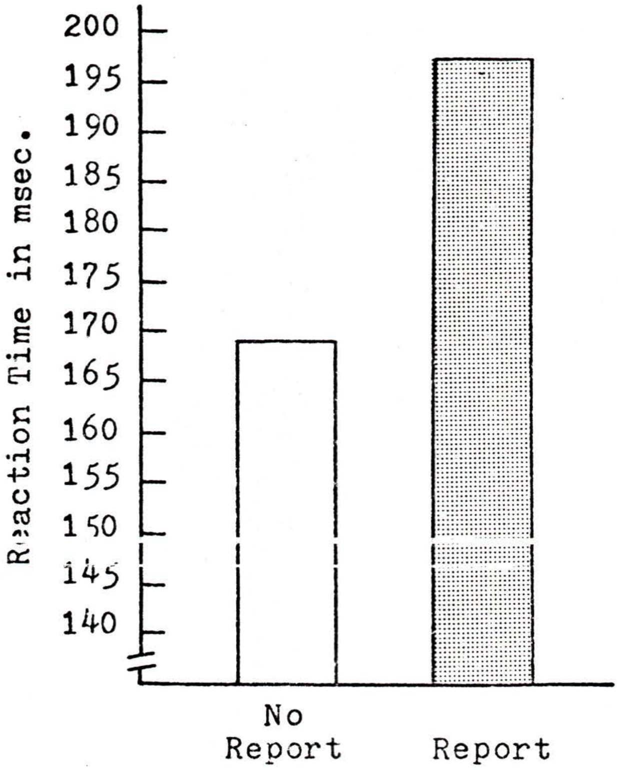

Figure 3. Report and No Report reaction times for S̲s in the Tone condition using their left hand.

Table VI

ANOVA for the three factors: Presentation, Report and Ears for Ss using their left hand in the Tone condition

Source	df	Mean Square	F
Presentation	1	0.00021	0.03
Report	1	0.02904	4.04*
Presentation x Report	1	0.02343	3.26
Error	44	0.00719	
Ears	2	0.00021	1.32
Ears x Presentation	2	0.00025	1.54
Ears x Report	2	0.00010	0.60
Ears x Presentation x Report	2	0.00002	0.15
Error	88	0.00016	
Total	120		

* $p < .05$

Table VII

ANOVA for the three factors: Presentation, Report and Ears for *Ss* using their right hand in the Complex Tone condition

Source	*df*	Mean Square	F
Presentation	1	0.00111	0.11
Report	1	0.03145	3.13
Presentation x Report	1	0.03591	$3.58^{\square}$
Error	44	0.01004	
Ears	2	0.00003	0.11
Ears x Presentation	2	0.00010	0.44
Ears x Report	2	0.00020	0.85
Ears x Presentation x Report	2	0.00006	0.26
Error	88	0.00024	
Total	120		

$^{\square}$ $p < .06$

Table VIII

ANOVA for the three factors: Presentation, Report and Ears for Ss using their left hand in the Complex Tone condition

Source	df	Mean Square	F
Presentation	1	0.00010	0.01
Report	1	0.02973	2.74
Presentation x Report	1	0.03025	2.79
Error	44	0.01085	
Ears	2	0.00021	0.73
Ears x Presentation	2	0.00038	1.36
Ears x Report	2	0.00002	0.07
Ears x Presentation x Report	2	0.00013	0.48
Error	88	0.00028	
Total	120		

Table IX

ANOVA for four factors: Presentation, Report, Ears and Hands for Ss in the Complex Tone condition

Source	df	Mean Square	F
Presentation	1	0.00099	0.05
Report	1	0.06070	3.01
Presentation x Report	1	0.06525	3.23
Error	44	0.02019	
Ears	2	0.00017	0.48
Ears x Presentation	2	0.00031	0.88
Ears x Report	2	0.00008	0.24
Ears x Presentation x Report	2	0.00014	0.38
Error	88	0.00035	
Hands	1	0.00062	0.89
Hands x Presentation	1	0.00025	0.35
Hands x Report	1	0.00002	0.03
Hands x Presentation x Report	1	0.00016	0.12
Error	44	0.00070	
Ears x Hands	2	0.00006	0.39
Ears x Hands x Presentation	2	0.00013	0.79
Ears x Hands x Report	2	0.00013	0.77
Ears x Hands x Pres x Rep	2	0.00008	0.51
Error	88	0.00016	
Total	240		

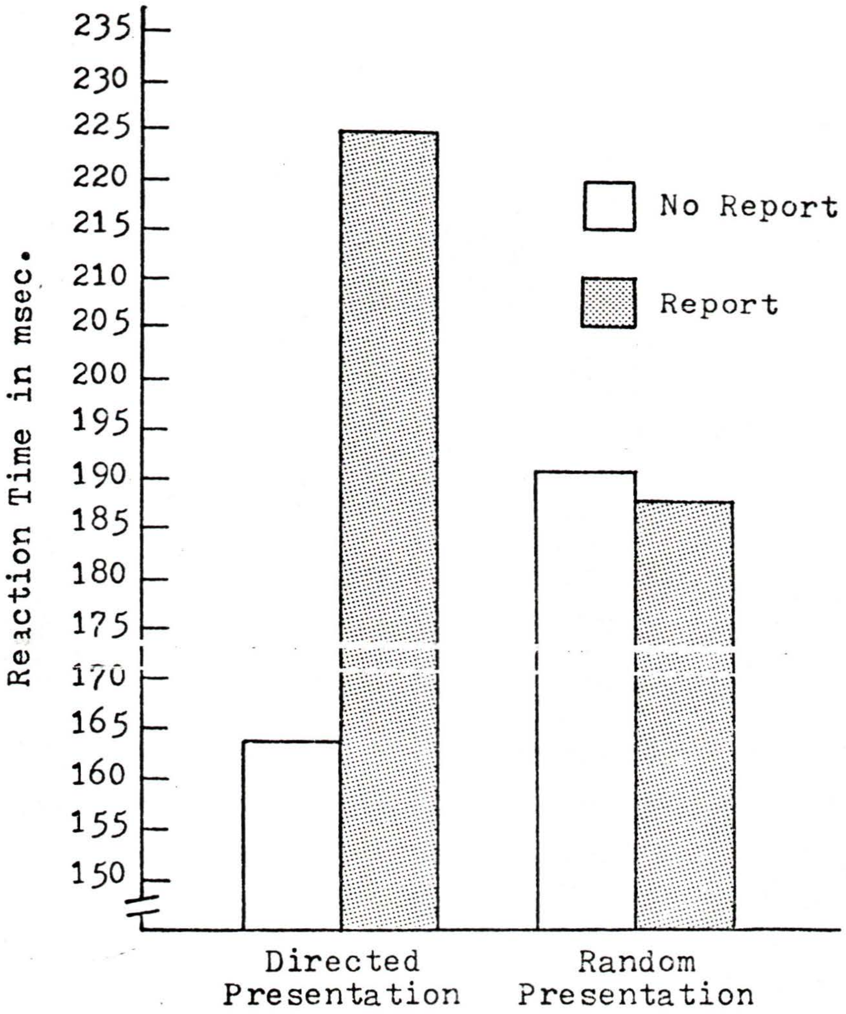

Figure 4. Presentation and Report reaction times for S̲s in the Complex Tone condition using their right hand.

faster left ear RTs in the ears main effects for both the right and left hands.

Language condition (L): both hands. The ANOVA for both hands (See Table X) revealed a significant report main effect ($F_{1,44}=8.27$, $p<.01$) a significant ears main effect ($F_{2,88}=15.85$, $p<.001$) and a significant hands main effect ($F_{1,44}=10.73$, $p<.01$). Also, there was a significant hands by presentation interaction ($F_{1,44}=5.23$, $p<.05$) and a significant hands by report interaction ($F_{1,44}=6.89$, $p<.01$). The significant hands by presentation interaction which is shown in Figure 5 was a result of S's superior right hand performance in the RP condition. Examination by a t test revealed no significant difference between left and right hand RTs in the DP condition (see Table XI). In the RP condition however, right hand RTs were significantly faster than left hand RTs. For the left hand there was no significant differences between RP and DP RTs, but with the right hand RP RTs were significantly faster than DP RTs.

The hands by report interaction shown in Figure 6 was a result of the faster RTs for N Rep Ss and the superior right hand RTs for Ss in the Rep condition. Examination by a t test revealed no significant difference between the left and right hands of N Rep Ss. In the Rep group however, right hand RTs were significantly faster than those of the left hand. Both the right and left hand N Rep RTs were faster than Rep RTs (see Table XII).

Table X

ANOVA for four factors: Presentation, Report, Ears and Hands for Ss in the Language condition

Source	df	Mean Square	F
Presentation	1	0.00450	0.10
Report	1	0.35765	8.27**
Presentation x Report	1	0.03857	0.89
Error	44	0.04324	
Ears	2	0.02020	15.85***
Ears x Presentation	2	0.00254	2.00
Ears x Report	2	0.00100	0.78
Ears x Presentation x Report	2	0.00143	1.12
Error	88	0.00127	
Hands	1	0.01154	10.73**
Hands x Presentation	1	0.00563	5.23*
Hands x Report	1	0.00741	6.89**
Hands x Presentation x Report	1	0.00288	2.68
Error	44	0.00108	
Ears x Hands	2	0.00034	1.25
Ears x Hands x Presentation	2	0.00065	2.40
Ears x Hands x Report	2	0.00016	0.60
Ears x Hands x Pres x Rep	2	0.00057	2.10
Error	88	0.00027	
Total	240		

* $p < .05$

** $p < .01$

*** $p < .001$

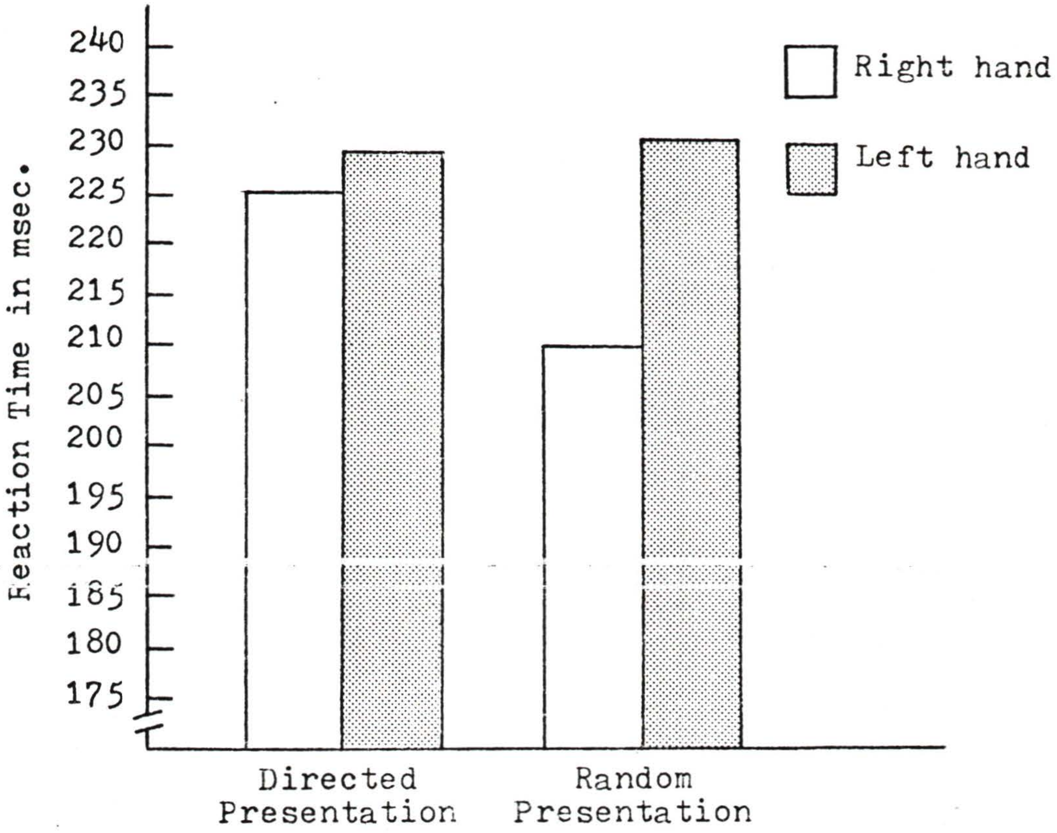

Figure 5. Presentation reaction times for Ss in the Language condition using their left and right hands.

Table XI

Means and t values for the Hands by Presentation interaction for Ss in the Language condition

	Hand		
	R	L	t
DP	.225	.229	.422
RP	.209	.230	2.213**
t	1.686*	.105	

* p<.05

** p<.025

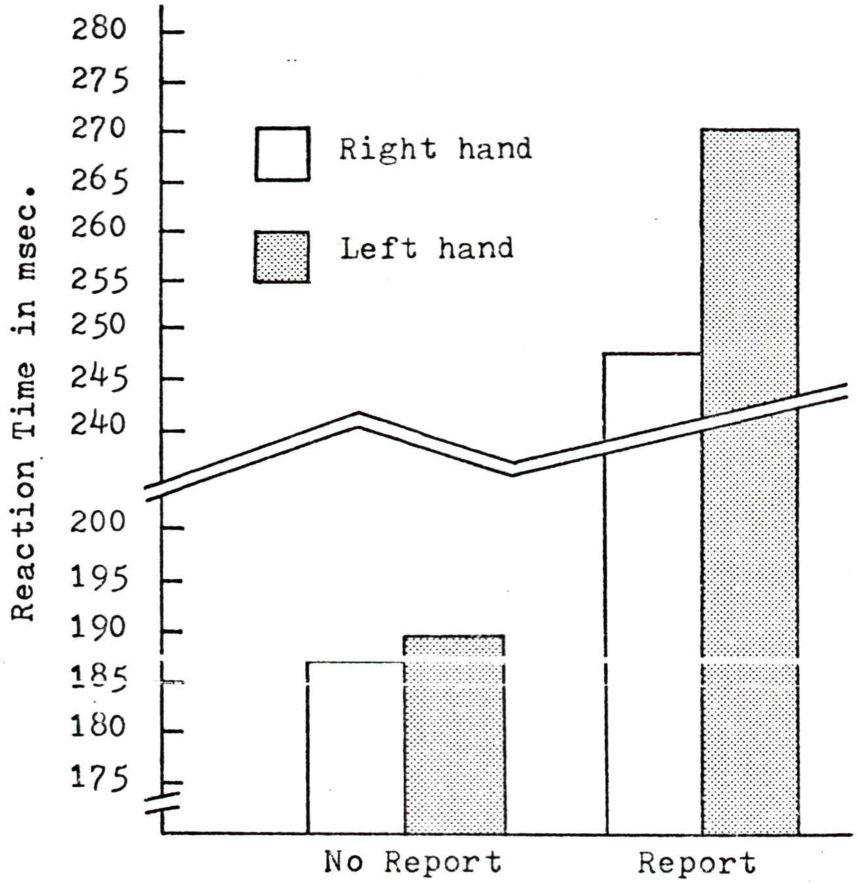

Figure 6. Report reaction times for Ss in the Language condition using their left and right hands.

Table XII

Means and _t_ values for the Hands by Report interaction for _S_s in the Language condition

	Hand		
	R	L	_t_
No Rep	.187	.189	.211
Rep	.247	.270	2.424**
_t_	6.322***	8.535***	

** $p < .01$

*** $p < .001$

The ears main effect is shown in Figure 7. The difference between the left and right ears was not significant, however diotic RTs were slower than those of left or right ears as determined by a _t_ test.

Language condition (L): right hand. The ANOVA for the right hand (see Table XIII) revealed a significant report main effect ($F_{1,44}=6.73$, $p<.01$), a highly significant ears main effect ($F_{1,44}=11.05$, $p<.001$), and a significant ears by presentation interaction ($F_{2,88}=2.00$, $p<.05$). This interaction which is shown in Figure 8 was a result of the combination of a superior right ear performance of _S_s in the RP group and the inferior performance of both ears of _S_s in the same group. Examination by a _t_ test of this interaction confirmed the hypothesis of no difference between the left, right and both ears of _S_s in the DP group (see Table XIV). It was interesting to note however that diotic RTs in the DP group were considerably slower than those for either the left or right ear. While in the hypothesized direction, the difference between the left and right ears in the RP group did not achieve significance ($t_{44}=1.032$, $p<.15$). However, the right ear RTs of _S_s in the RP group were faster ($t_{88}=2.649$, $p<.005$) than those for _S_s in the DP group. The differences between the left ear and both ears of the two presentation groups did not approach significance. Both ear RTs for _S_s in the RP group were significantly slower than those for the left ear or those for the right ear. This

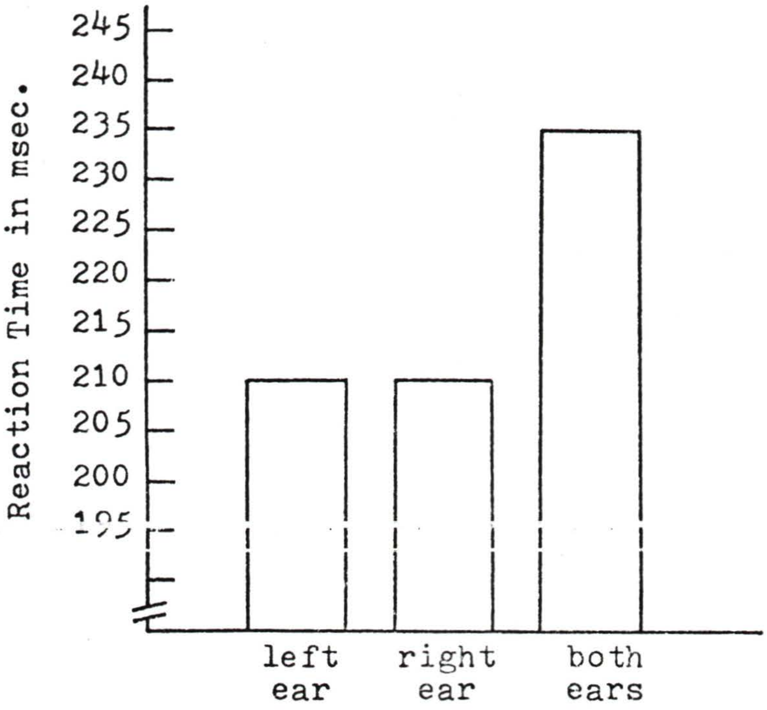

Figure 7. Left, right, and both ear reaction times for Ss in the Language condition using their left and right hands.

Table XIII

ANOVA for the three factors: Presentation, Report and Ears for Ss using their right hand in the Language condition

Source	df	Mean Square	F
Presentation	1	0.01010	0.52
Report	1	0.13104	6.73**
Presentation x Report	1	0.03127	1.61
Error	44	0.01948	
Ear	2	0.00807	11.05***
Ear x Presentation	2	0.00219	2.00*
Ear x Report	2	0.00063	0.86
Ear x Presentation x Report	2	0.00046	0.63
Error	88	0.00073	
Total	120		

* $p < .05$

** $p < .01$

*** $p < .001$

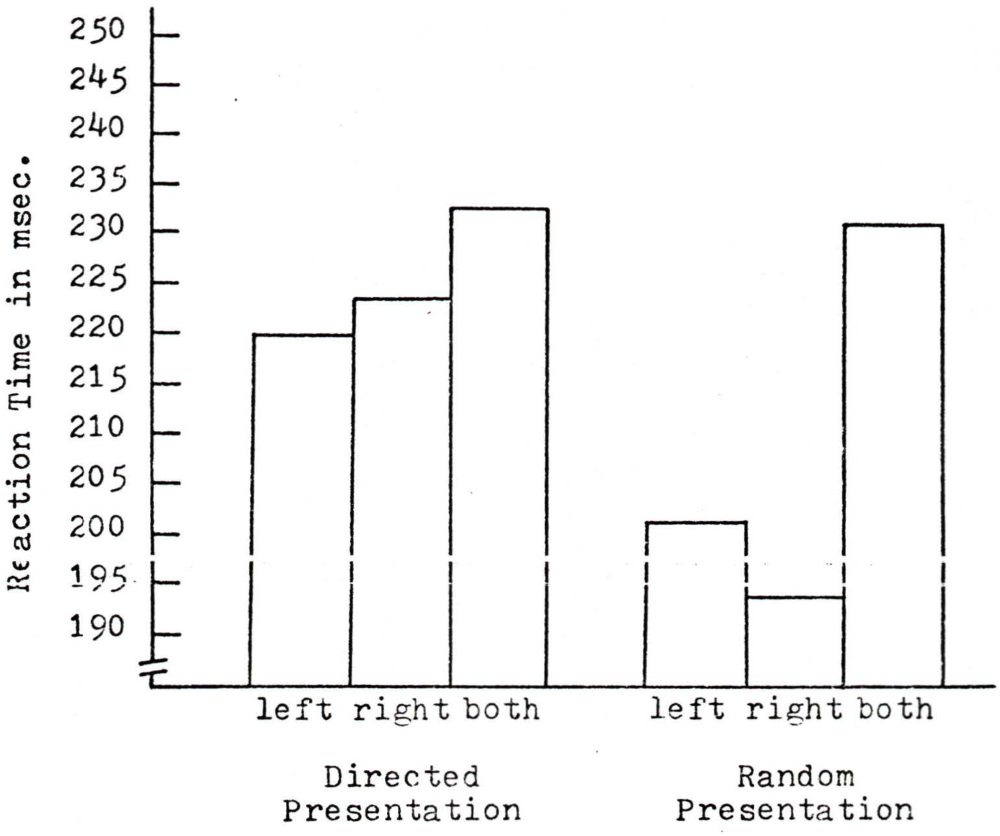

Figure 8. Presentation reaction times for the left, right, and both ears for Ss in the Language condition using their right hand.

Table XIV

Means and *t* values for the Ears by Presentation interaction for *S*s using their right hand in the Language condition

	Ears					
	L	R	t_{44}	R	B	t_{44}
DP	.220	.223	.387	.223	.233	1.290
RP	.202	.194	1.032	.194	.231	4.774***
t_{88}	1.644	2.649**		2.649**	.183	

** $p < .01$

*** $p < .001$

finding was not expected nor was it in the hypothesized direction. The report main effect (see Figure 9) confirmed the hypothesis that the N Rep RTs are significantly faster than the Rep RTs.

The data from the L condition provided support (albeit less direct than that of the T condition) for the hypotheses that there is no difference between the left, right, and both ears in the DP condition and that right ear RTs are faster than left ear RTs in the RP condition. The hypothesis that both ear RTs are faster than right or left ear RTs in the RP group was not supported. The hypothesis that RP RTs are slower than DP RTs also was not supported, and in one instance (the right ear) the RP RTs were significantly faster than the DP RTs.

Language condition (L): left hand. The ANOVA for the left hand (see Table XV) revealed a significant report main effect ($F_{1,44}=9.42$, $p<.01$) and a significant ears main effect ($F_{2,88}=15.29$, $p<.001$). The report main effect was in the hypothesized direction with N Rep Ss faster than Rep Ss (see Figure 10). The ears main effect (see Figure 11) revealed no difference between the left and right ears but diotic RTs were significantly slower than either those for the left or right ear ($t_{88}=2.57$, $p<.005$). The asymmetry and presentation hypothesis were not supported by the left hand data.

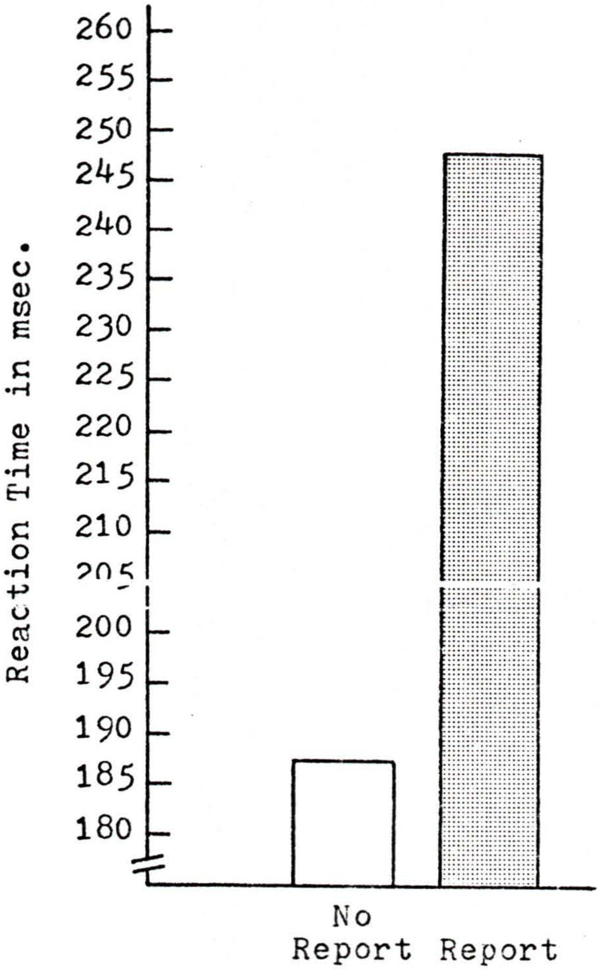

Figure 9. Report and No Report reaction times for Ss in the Language condition using their right hand.

Table XV

ANOVA for the three factors: Presentation, Report and Ears for Ss using their left hand in the Language condition

Source	df	Mean Square	F
Presentation	1	0.00003	0.01
Report	1	0.23401	9.42**
Presentation x Report	1	0.01018	0.41
Error	44	0.02483	
Ears	2	0.01248	15.29***
Ears x Presentation	2	0.00100	1.23
Ears x Report	2	0.00053	0.65
Ears x Presentation x Report	2	0.00154	1.88
Error	88	0.00082	
Total	120		

** $p < .01$

*** $p < .001$

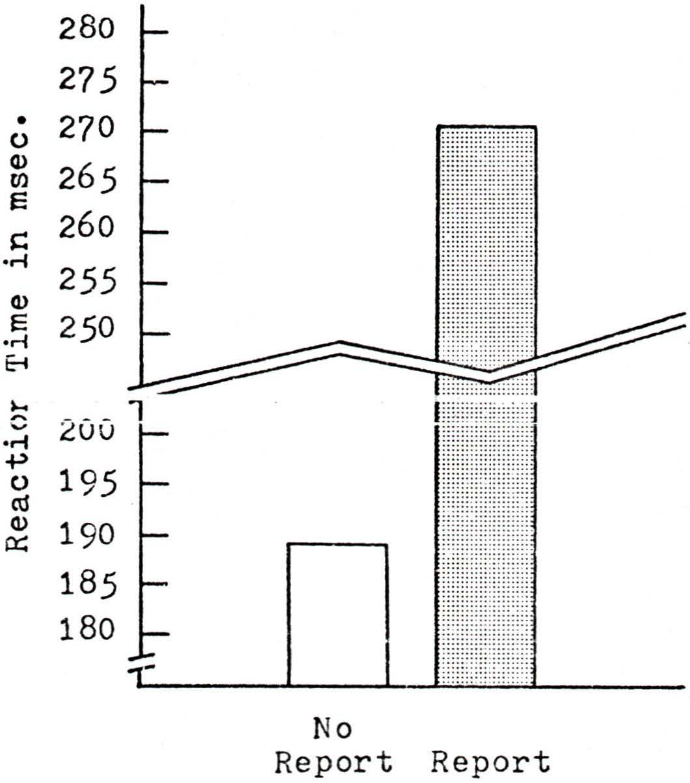

Figure 10. Report and No Report reaction times for S̲s in the Language condition using their left hand.

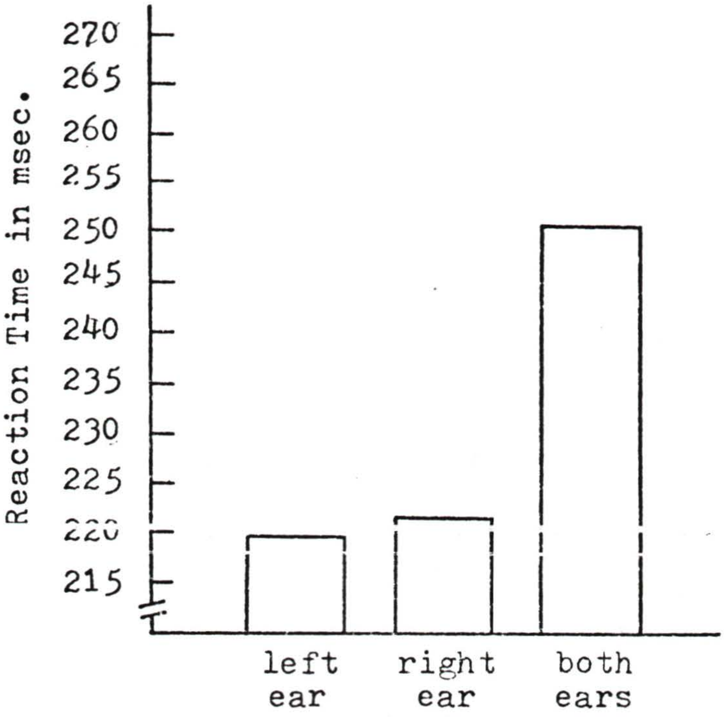

Figure 11. Left, right, and both ear reaction times for Ss in the Language condition using their left hand.

Discussion

The data from the T and L sound conditions are consistent with Simon's (1967) study. The RP Ss in both of these conditions showed a right ear preference. However, this trend was only noted when the right hand was used. The hypothesis that diotic RTs would be faster than either left or right ear RTs was supported with N Rep Ss in the T condition but this difference did not achieve significance. Diotic RTs for Rep Ss in the T condition and for both RP and DP Ss in the L condition were in the opposite direction of what had been hypothesized. These ear differences and hand differences each merit comment as do the unexpected effects of reporting and the failure of the CT condition to show any consistent differences. Findings will be discussed separately for each of the sound conditions. The right ear preference shown by Ss in the T and L conditions is the first instance of such a preference for both a language and non-language task within the same Ss. Such a finding has not previously been reported.

Tone Condition

Directed presentation, no report. The N Rep Ss using their right hand in the DP group were involved only in a detection task. When informed that the tone was to be delivered to the right ear attention was focused to the contralateral pathway. When informed that the tone was to be delivered to the left ear it was assumed that attention was focused to the ipsilateral pathway hence detection occurred also in the left hemisphere. (See Figure 12.) Had the left ear input also followed the contralateral pathway the impulse would have gone first to the right hemisphere then across the corpus callosum. Had this been the case, one might expect left ear RTs to be significantly slower than right ear RTs in the DP condition. This, however, was not the case. This finding is taken as evidence for the efficiency of the ipsilateral pathway in the absence of competition. When DP N Rep Ss were informed that the tone was to be delivered diotically no significant difference was found between diotic and left or right ear RTs. In this situation the S could selectively attend to either the contralateral or the ipsilateral pathway.

Apparently when Ss are asked to use their left hand in the auditory detection task, the right hemisphere mediates the response (see Figure 13). This is the analogue of the situation where the right hand is used. The implication is that either hemisphere is capable of emitting a response in an auditory detection task. This explanation accounts for the finding of no differences between the left and right hands and left, right, and both ears in a directed presentation situation.

As an alternative explanation, it could be argued that detection occurred within the dominant left hemisphere and impulses were then sent across the corpus callosum where a

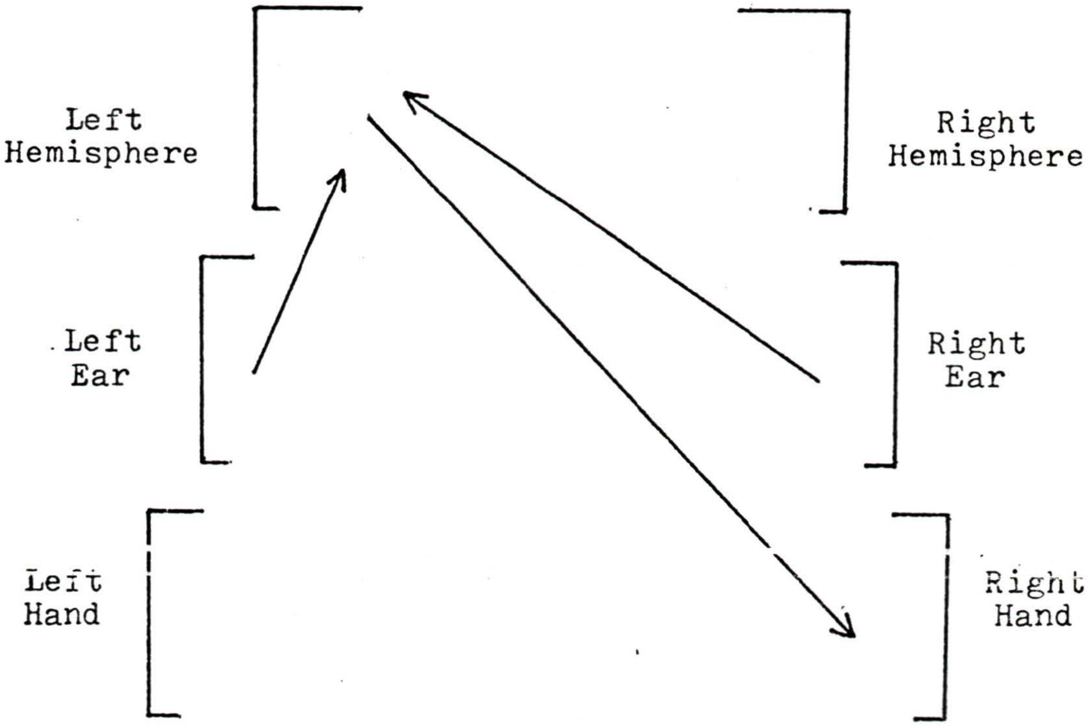

Figure 12. Neural pathways employed in the Directed Presentation condition when Ss are responding with their right hand.

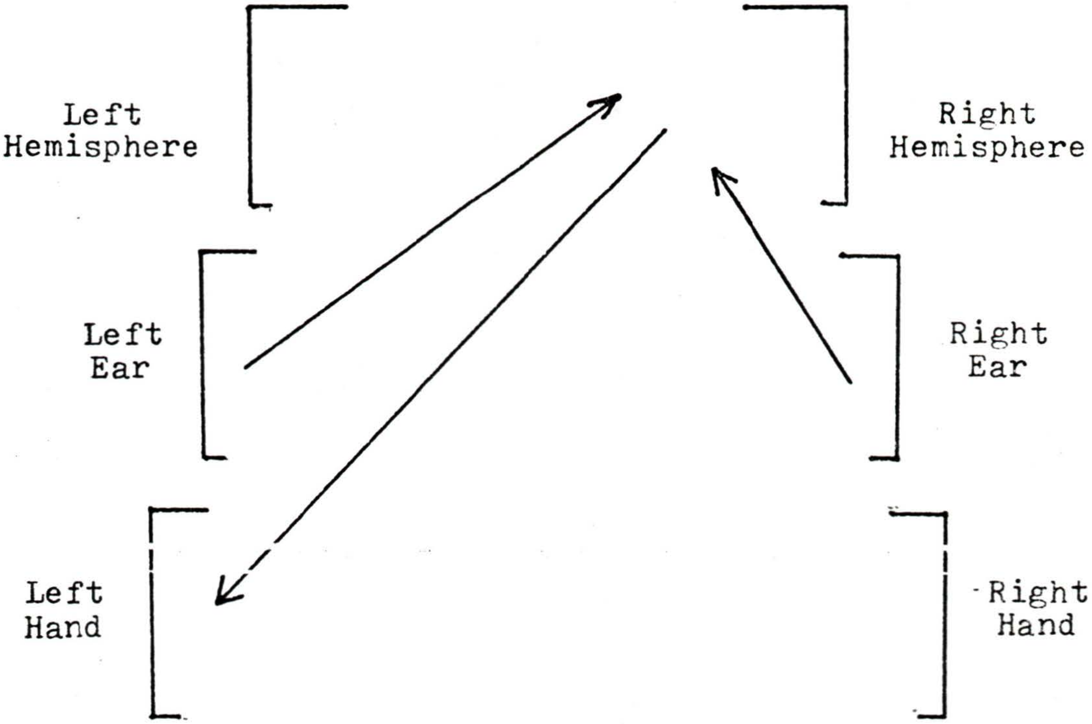

Figure 13. Neural pathways employed in the Directed Presentation condition when Ss are responding with their left hand.

left hand response was effected. Had this been the situation, then left hand RTs should have been significantly slower than right hand RTs. This, however, was not the case. The ANOVA in which hands were taken out as a factor showed no such differences and a comparison of the separate left and right hand ANOVAs revealed no differences. The first explanation provides a better account of the data.

Random presentation, no report. The *S*s in this condition did not have the advantage of knowing which ear was to be stimulated. As hypothesized, right ear RTs were significantly faster than left ear RTs and diotic RTs were faster than either the left or right, however, this difference did not reach significance. These findings were obtained only for the right hand. The explanation of equal efficiency of the ipsilateral and contralateral pathways as offered above does not apply in this condition. If that explanation also applied to the RP condition there should have been no difference between ears, however, such was not the case. Rather, when the *S* was in doubt, attention was focused on the contralateral pathways. (See Figure 14.) If the auditory detection task was more efficiently accomplished in one hemisphere, then RT to stimulation of the contralateral ear should have been faster. The right ear was significantly faster than the left indicating that detection occurred in the left hemisphere.

This is not to imply that the right hemisphere was

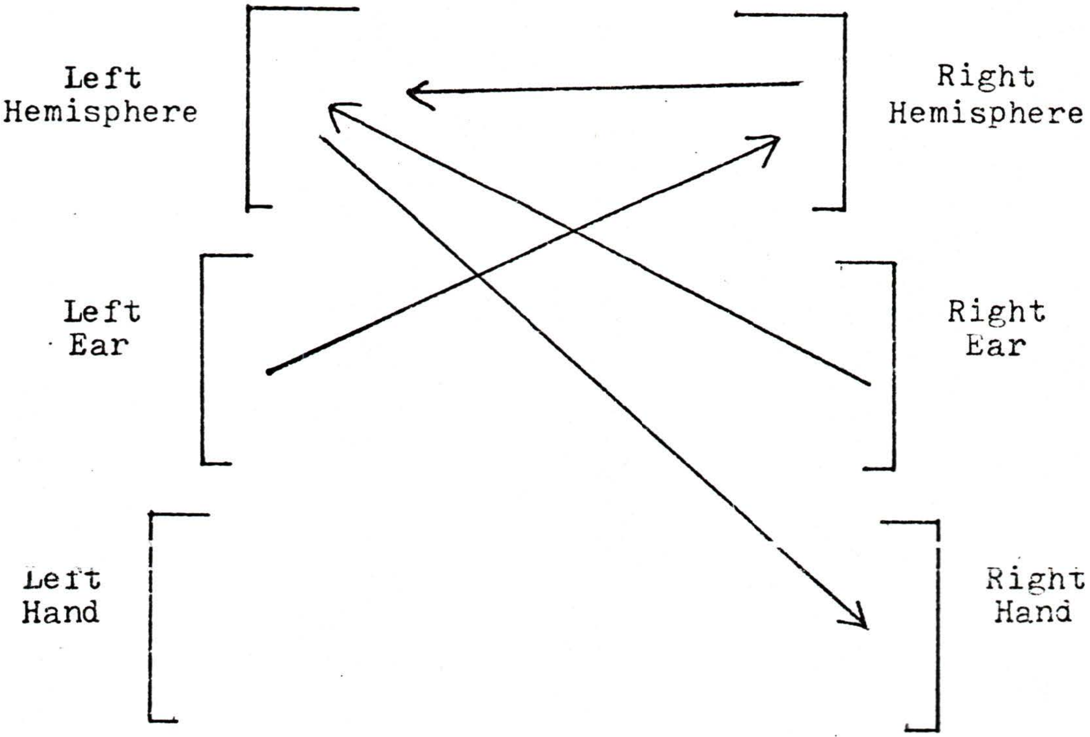

Figure 14. Neural pathways employed in the Random Presentation condition when Ss are responding with their right hand.

incapable of detection in the RP situation. Rather, it demonstrated that the left hemisphere was more efficient. Following the attention model detailed above, these asymmetries could be explained by either the superior contralateral pathways to the dominant hemisphere or as a result of some unequal distribution of attention between the two ears. Considering the above definition of attention offered by Treisman (1969), it is suggested that these two explanations are the same.

Right hand responses originate in the pre-motor area of the left hemisphere. The efferent tracts descend in the internal capsule to the pyramids of the medulla oblongata where an estimated 80 per cent decussate and descend as the lateral corticospinal (pyramidal) tracts. The finding that the right hand should be more efficient with a left hemisphere detection certainly seems reasonable. Because of this it could be argued that the superior performance of the right ear was due to the fact that Ss were required to respond with their right hand. What this argument does not explain however is why the right ear was more efficient. Rather, an explanation which emphasizes the unequal distribution of attention favoring the dominant hemisphere appears to offer more explanatory power. If the right hand left hemisphere explanation were to be adopted, then the opposite findings should be noted when the S is required to use his left hand. The data however do not support this argument. One might speculate that using the left hand, the left hemisphere is still dominant, however any advantage the right ear might enjoy is lost as the left hemisphere detection must cross the corpus callosum to the right hemisphere to effect a motor response.

When the S's attention was divided and the tone was delivered to both ears the RTs should at least be as fast as when the tone was delivered to the right ear. This was explained by the fact that the signal always hit the dominant right ear. The finding that diotic RTs were faster than monaural trials in this detection task may be explained by the fact that RT is a function of intensity (Woodworth and Schlosberg, 1954) and diotic stimulation is of greater intensity.

The effect of reporting, RP and DP. The effect of reporting resulted in considerably slower RTs for DP Ss. This effect was not noted in RP Ss nor was it in the hypothesized direction. The Ss in the Rep DP condition showed no significant difference between their left and right ears. This suggests that the same mechanism was operating as with N Rep DP Ss (see Figure 12). The RTs to diotic stimulation however, were significantly faster than either those for the right or left ear. Further, Rep DP right and left ear RTs were considerably slower than those for the Rep RP condition. In terms of the left and right ears it appeared as if prior knowledge of the ear to be stimulated inhibited performance while lack of prior knowledge seemed to facilitate performance. This explanation may account for the finding that reporting did not increase asymmetry as had been hypothesized. This did not appear to be the case however when both ears were stimulated. (It will be recalled that the non-significant presentation by report interaction in the CT condition also indicated that the effect of reporting was to increase RT for DP Ss and not for RP Ss.)

An explanation for this rather curious finding that prior knowledge inhibited RTs of Rep Ss would be that knowledge that the left or right ear was to be stimulated actually increased task difficulty. The Ss must not only attend to the left or right ear but must also attend to the discrimination task imposed by the report requirement. The Ss in the RP Rep condition did not have the additional task of attending to the left or right ear imposed on them. Rather they only had to directly attend to the discrimination task and could selectively attend with the contralateral pathway to the dominant hemisphere. The observed asymmetry between the left and right ears for RP Rep Ss may be explained by same model as for RP N Rep Ss, i.e., when Ss were in doubt as to which ear would be stimulated, they selectively attended with their contralateral ears (see Figure 14).

A perhaps useful distinction between what might be termed directed attention and selective attention has been introduced to account for the inferior performance of *S*s required to report who had been told in advance which ear was to be stimulated. Support for this distinction may be found in the experiment reported above by Spellacy and Blumstein (1970a). In that study it was found that when *S*s attend to vowels and consonants in a language context a right ear superiority was found for the consonants but not the vowels. However, when *S*s attended to the same sounds in a non-language context there was a left ear superiority for vowels but the consonants still showed a right ear superiority. Thus despite the contextual cues (directed attention) in the non-language condition the selective attention for consonants still revealed a right ear superiority. In the present experiment *S*s could selectively attend in the RP Rep condition and needed only concern themselves with the discrimination task. In the DP Rep condition *S*s could not selectively attend, rather they had been directed to attend to the left or right ear as well as concern themselves with the discrimination task. Selective attention principles are believed to be in accord with the principles of cerebral dominance and, as discussed later in the section on language reporting, selective attention may be more efficient than directed attention.

Selective attention principles may also be employed to account for the finding that RP Rep *S*s showed slower diotic

RTs than right ear RTs and only slightly better than left ear RTs. Above it was suggested that in the RP situation attention was focused on the contralateral pathways. In the Rep condition however, Ss not only had to detect but also had to discriminate (i.e., was the tone the same as or different than the previous one?). One explanation is that this two-step process was taken successively, not simultaneously. An alternative explanation is that this discrimination task employed a different set of analyzers than the simple detection task. If the two-step process had been followed the RP Rep RTs should have been slower than RP N Rep RTs. This, however, was not the case. Rather, S's RTs in the RP Rep condition for their left and right ears were equally efficient if not slightly better than the RTs for RP N Rep Ss. This indicated that the discrimination analyzers were slightly (but not statistically) more efficient than the detection analyzers when stimulation was delivered to only one ear. The increased efficiency of these discrimination analyzers could also explain the failure of the RP Rep condition to increase left-right asymmetry. The discrimination analyzers however, may depend on the offset of the stimulus. This is not to be confused with the two-step processing model cited above.

It has been suggested that in the RP conditions (Rep and N Rep) that when the tone was delivered to the right ear it was carried directly to the dominant left hemisphere and a response was emitted. When the tone was delivered to the left ear it was transmitted to the right hemisphere then relayed across the corpus callosum to the left hemisphere where a response was emitted. When the tone was presented to both ears in the RP N Rep condition it was suggested that the same process was followed as when the tone was presented to the right ear. However, when the S̲ was to report in the RP condition to diotic stimulation there appeared to have been a slight inhibiting effect. In this situation an impulse was received from the dominant right ear followed immediately by an impulse coming from the non-dominant left ear. It is posited that the discrimination analyzers are more sensitive to perceptual confusion than the detection analyzers. In the discrimination task it is suggested that some cerebral processing is taking place; a processing not required in the detection task. Since the S̲s were attending to both ears (albeit to a lesser extent with the left) it may be that both signals were processed. Hence diotic RTs were almost the same as left ear RTs (186 vs. 188 msec.). It could be argued that the response was being made to the second tone (i.e., the left ear). This would be in keeping with the finding that in dichotic listening tasks in which the signal is lagged to one ear S̲s prefer the lagged as opposed to the led ear (Studdert-Kennedy, Shankweiler and Schulman, 1970). It is apparent from this explanation that the intensity differences used to account for the efficiency of diotic stimulation in the RP N Rep condition did not apply in a discrimination task.

The superior diotic RTs of Ss in the DP Rep condition may be accounted for by a similar explanation. Since Ss had been informed that the tone would be coming to both ears as opposed to either the left or right ear, they needed not directly attend to one ear or the other. Rather, they could have selectively attended with the dominant right ear. This decrease in task difficulty accounts for the superior diotic RTs. However, it was still noted that diotic RTs for DP Rep Ss were considerably slower than those for Ss in the DP N Rep condition. This was accounted for by the fact that the S was involved in a discrimination task not a detection task. Thus it is not surprising that DP Rep Ss were not significantly different from RP Rep Ss (193 vs. 186 msec.).

It has been consistently noted that the above explanations apply only to the right hand. Mechanisms mediating the left hand responses however, have been suggested. In the DP condition it has been proposed that left hand responses follow similar mechanisms such as have been proposed for the right hand. In this case, detection is believed to occur in the non-dominant right hemisphere. In the RP condition it has been suggested that the discrimination occurs more efficiently in the dominant left hemisphere hence any advantage the right ear might have enjoyed was lost since impulses must travel the corpus callosum to effect a left hand response. Reporting had an equally disruptive effect on left hand RTs as supported by the significant left hand report main effect shown in Figure 3.

In this discussion a distinction has been made between detection and discrimination tasks. Empirical verification from the right hand data and the less clear left hand data suggests that both hemispheres are equally capable of either task when the S's attention is directed and when the stimulus is a pure tone. In the following sections however, it is proposed that the left hemisphere is dominant for more complex discrimination tasks when the stimulus is phonemic in nature even when the S's attention is directed.

Language Condition

The evidence for a right ear superiority in the L condition is less conclusive than in the T condition. Using their right hand Ss in the DP condition, as hypothesized, showed no significant difference between their left and right ears. In the RP condition right ear RTs were faster than left ear RTs, however, the difference did not quite reach significance (202 vs. 194 msec.). This difference of 8 msec. was significant in T condition. The ears by presentation interaction revealed no significant differences between the left ear and diotic stimulation of Ss in the DP and RP groups. For the right ear, however, the RP RTs were significantly faster than DP RTs. This interaction is accepted as evidence for a right ear superiority for Ss in the RP condition even though the primary hypothesis (i.e., that the right ear would be faster than the left ear) was not directly supported.

Left and right hands. The significant hands by presentation interaction and the hands by report interaction clearly indicated a distinction between the left and right hands. This finding was not in the hypothesized direction. Considering the hands by presentation interaction it was apparent that there was no significant difference between the left and right hand when presentation was directed. In the RP condition however, the right hand was significantly faster than the left. Of further interest was the finding that the right hand RP RTs were significantly faster than DR RTs for either the right or left hand. With the left hand, however, there was no difference between DP and RP RTs. Apparently right hand efficiency (i.e., the left hemisphere) varies as a function of attention. Following the argument detailed above it appears that when presentation was directed either hemisphere was equally capable of effecting a response. However, when presentation was random, the hand contralateral to the dominant hemisphere was facilitated. The effect of prior knowledge in these tasks not only eliminated any differences between the two hands but also inhibited the performance of the dominant hand. Directed attention to a given ear(s) as well as to the detection or discrimination problem increased task difficulty compared to the situation where attention was directed only to the detection or discrimination problem and the S could selectively attend with his ears.

The hands by presentation interaction suggested no distinction between Rep and N Rep Ss. The hands by report interaction, however, suggested that the detection and discrimination analyzers were operating differently. N Rep Ss were significantly faster than Rep Ss with either hand and there was no difference between their left and right hands. This is taken as further evidence for the equipotentiality of the left and right hemispheres in a detection task even when the stimulus is language. Rep Ss, who were considerable slower than N Rep Ss, showed a difference between their left and right hands. Right hand RTs were significantly faster than those for the left.

A possible, but unlikely, explanation for the slower RTs of Ss in the Rep condition would be that a two-step process of detect then discriminate was being followed. This explanation was rejected in the T condition since the inhibiting effect of reporting was not apparent with RP Ss. While the same evidence was not available in the L condition this two-step process was also rejected. Rather, it is suggested that the analyzers employed in the discrimination task are analagous to Spellacy and Blumstein's (1970a) frequency analysis or Studdert-Kennedy and Shankweiler's

(1970) linguistic device. Since the S was not being asked to detect the mere presence of sound but rather must process the CVC word in some manner, he was dependent on the temporal arrival of the phonemic information carried by the word. This was not required in the T condition. The word which is of finite length may be processed only as fast as it arrives. As the processing is completed a response may be simultaneously emitted. Thus RT in the Rep condition was a function of word length.

The explanation that Rep Ss responded to the offset of the word does not account for the superior right hand performance. The well documented role of the left hemisphere in language perception does, however, explain this finding. Thus the hand contralateral to the dominant hemisphere is superior to the ipsilateral hand. Since this phenomenon does not seem to be affected by the ear of report or presentation condition the implication is that the perception of the CVC word in Rep Ss occurs strictly in the left hemisphere. Support for this is gained by examining separately the report main effects for the left and right hands (see Figures 9 and 10). The RTs for the N Rep right and left hand trials were 187 and 189 msec. respectively. For the Rep trials, however, the RTs were 247 msec. for the right hand and 270 msec. for the left hand. This finding demonstrates the power of selective attention and is consistent with the data reported by Spellacy and Blumstein

(1970a). Despite directed attention sets provided by instructions (e.g., "use your left hand" or, "the word will be coming to your left ear") *S*s still selectively attended with the dominant hemisphere. Thus the equipotentiality of either hemisphere to perform a discrimination task as noted in the T condition was absent when the stimulus was language and the *S* was reqired to report.

Ears, directed and random presentation. The right ear preference noted above was evident only when *S*s used their right hand. The difference between the left and right ears in the DP condition was, as expected, not significant. As in the T condition, it is suggested that when the *S* has prior knowledge that the CVC word will come to the right ear he is able to focus his attention on the contralateral neural pathway. When informed that the word will come to his left ear he is able to focus his attention on the ipsilateral neural pathway. When the *S* does not know what ear is to be stimulated there is a definite trend favoring the right ear. As in the T condition, it is suggested that the *S* is attending with the contralateral neural pathways. When the word is presented to the right ear the connection is direct to the left hemisphere. When the word is presented to the left ear the less direct contralateral path to the right hemisphere is followed. From the right hemisphere the impulse must cross the corpus callosum to the dominant hemisphere (see Figure 14). The 8 msec. difference noted in both the T and L conditions may represent the time needed to cross the corpus callosum. Efron (1963) has suggested that the time needed to cross the corpus callosum for the visual and tactile modalities is from 2 to 6 msec. Efron argued that this interval probably holds for all sensory modalities except audition. With the auditory mode he believes that the detection of temporal arrival occurs in the first or second synapse of the auditory pathways in the brain stem. As a result of this he argued that any attempted analysis for asymmetry at higher levels in the auditory nervous system would be impossible. The data presented in this experiment refute this position.

The DP RTs for the left and right ears were considerably slower than those for the left and right ears of RP _S_s. This difference, which was highly significant for the right ear, indicates that prior knowledge of which ear is to be stimulated inhibits performance. This same finding was noted in the T condition for DP _S_s who were required to report. It was suggested that when the discrimination analyzers are being used and presentation is directed, RTs are hindered. The same explanation holds in the L condition except that RTs are hindered regardless of whether detection or discrimination analyzers were being used.

When the words were presented diotically, RTs for both RP and DP _S_s were slower than those for either the right or left ear. This difference was not significant in the DP condition but was highly significant in the RP condition. In the RP condition a perceptual confusion situation is suggested. This perceptual confusion was a result of the diotic stimulation. The processing of the CVC word required a perception over some finite period of time. As the phonemic information from the right ear was being processed the information arrived from the left ear via the corpus callosum (on the order of 8 msec. later). In the resulting disruption the *S*s had to sort out to which signal he would respond. An explanation which is consistent with the ear lag phenomenon and the explanation offered in the T condition is that when the second signal arrived the *S*s returned to the starting point and began the discrimination process all over. Thus it appears that it was the second signal, the word arriving from the non-dominant ear, to which the *S* was responding.

A possible explanation for this rather curious finding is contained in the distinction between diotic and binaural stimulation. In diotic stimulation one signal is received by the two ears at the exact same time. The stimuli presented to both ears in this experiment was clearly of a diotic nature. In binaural stimulation, the same signal is also received by both ears but there may be phase, intensity, and frequency differences. In normal day to day hearing, it would seem that hearing is binaural.

The same mechanisms are suggested to be operative for

Ss in the DP condition. Here, however, the perceptual confusion was less obvious since Ss using their right and left ears already had RTs attenuated by having had attention directed to the specified ear.

The failure to note any asymmetries between the left and right ears when Ss were using their left hand is accounted for by the same explanation as offered above in the T condition. It seems likely that when Ss were using their left hand, discrimination occurred in the left hemisphere. Any advantage the right ear might have enjoyed, however, was lost as impulses had to cross the corpus callosum to effect a left hand response. If auditory perception was equal bilaterally, a left ear advantage should have been noted when Ss were using their left hand. The finding that diotic stimulation was equally inhibiting for left hand RTs was apparent from the left hand, ears main effect (Figure 11).

Complex Tone Condition

The failure of the CT condition to support any of the hypotheses (except that of no difference between the left, right and both ears in the DP condition) is of some interest. A possible explanation may be contained within (a) the instructions the Ss received as well as in (b) the nature of the stimulus. The Ss in both presentation and report groups heard the first part of the pre-recorded instructions. They were told that there would be three tones used in the current test: a high, medium, and low tone. They then heard each tone presented twice. During their six practice trials they once again heard the three tones. At the end of the general instructions, before specific presentation or report instructions were given, the Ss once again heard the three tones going from high to low in immediate succession. This task has many parallels with the music and other non-language conditions which have been used to demonstrate a left ear (presumably right hemisphere) superiority. The three tones, when presented successively, resembled the Seashore Tonal Memory Test. In this condition however, no left ear preference was noted for RP Ss even when the report requirement was added. What was of more interest was the apparent lack of right ear preference. It appears as if Ss could not consistently selectively attend to these tones as they could to the pure single tone or the CVC words. Thus while the CT conditions do not support any of the asymmetry hypotheses, neither do they refute them. The notion that the CT condition may serve as a point on a gradient from the T to the L conditions is unjustified.

Attention and Asymmetry

One of the most consistent findings in this study was contained in the interactions involving presentation and the ears or the hands (Figures 2, 5 and 8) and in the hands by report interaction for the L condition (Figure 6). In all cases where the S's attention was directed or in those situations where the Ss were not required to report, there were no differences between the left and right ears or hands. This finding suggests an equipotentiality of either hemisphere. When presentation was not directed however, and the S was able to selectively attend there was always a preference for the right ear or hand. This left hemisphere superiority was noted in both a language and non-language related task. The finding for a right ear preference in the L condition is consistent with the notions of language perception and cerebral dominance. The finding of a right ear preference in both the T and L conditions indicates that the left hemisphere, which is dominant for language, is also dominant for some forms of non-language perception as well. The variations in RT between the two presentation conditions were consistently less for the left hand than for the right hand. The performance of the right hand varied as a function of attention, with superior RTs when Ss were selectively attending with the left hemisphere.

Attention appears to be a critical variable in this study. In most cases, except when the stimulus was a single pure tone, Ss performed better when they could selectively attend, i.e., when they could determine for themselves to which ear they would attend. The power of selective attention was perhaps best demonstrated in the hands by report interaction where it was noted that Ss selectively attended to the CVC word with the left hemisphere independent of directed presentation instructions. It appears that both the nature of the task as well as the nature of the stimulus and directed instructions may determine to what extent selective attention principles intervene.

This capacity to selectively attend to auditory stimulation appears to be a left hemisphere process in right handed Ss. In this respect auditory perception and selective attention are synonymous. This is not to deny the role of the right hemisphere in auditory perception, rather it is proposed that the degree of involvement of the right hemisphere in auditory perception is mediated by the processes of selective attention, i.e., the dominant left hemisphere. This view is compatible with Spellacy and Blumstein's (1970b) concept of a single active hemisphere in auditory perception.

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Appendix

Mean Reaction Time Right Hand

			Tone			Complex Tone			Language		
		EARS	Left	Right	Both	Left	Right	Both	Left	Right	Both
Directed Presentation	No Report	Ss 01	165	173	163	152	150	140	128	137	163
		02	139	150	138	151	132	144	143	149	186
		03	201	182	179	148	160	143	203	159	149
		04	153	143	146	139	153	129	149	151	152
		05	157	170	154	190	166	184	189	283	202
		06	198	182	184	213	210	210	242	226	296
		07	170	154	155	170	210	194	200	157	211
		08	135	128	137	136	146	135	139	151	185
		09	182	187	179	184	170	186	244	205	264
		10	150	156	165	182	179	176	146	159	162
		11	164	180	159	172	161	163	165	136	170
		12	121	128	127	132	140	143	131	160	209
	Report	13	146	147	150	137	148	164	170	157	174
		14	134	135	128	154	184	165	172	156	181
		15	182	173	162	142	146	158	213	211	236
		16	144	134	128	149	140	154	191	174	169
		17	148	154	134	184	197	177	201	183	178
		18	140	139	141	174	163	160	143	168	130
		19	204	212	212	221	262	244	217	254	224
		20	356	347	329	415	343	458	428	548	443
		21	214	199	215	233	248	260	340	291	317
		22	342	350	309	380	401	323	448	451	442
		23	328	295	225	261	275	271	332	310	377
		24	158	192	180	195	208	200	353	375	377

Mean Reaction Time Right Hand

			Tone			Complex Tone			Language		
		EARS	Left	Right	Both	Left	Right	Both	Left	Right	Both
Random Presentation	No Report	Ss 25	215	201	186	150	154	147	132	106	156
		26	210	197	203	185	181	178	132	188	260
		27	142	117	114	109	108	102	123	111	127
		28	169	181	156	152	147	153	144	179	151
		29	150	151	159	210	248	262	150	121	228
		30	179	185	172	271	266	271	137	151	156
		31	236	230	193	247	228	203	238	164	161
		32	230	226	213	225	227	217	271	279	308
		33	155	145	133	144	144	147	163	119	190
		34	201	188	202	193	190	186	189	235	231
		35	170	146	176	167	167	149	208	133	205
		36	255	223	247	242	249	211	332	359	422
	Report	37	178	176	174	151	142	149	154	118	144
		38	176	176	179	217	201	211	362	317	400
		39	192	163	200	157	150	143	159	149	195
		40	122	120	113	109	109	120	141	162	153
		41	137	130	131	154	158	188	142	121	139
		42	171	166	173	212	206	180	170	199	232
		43	256	251	260	297	282	308	245	254	309
		44	194	191	200	189	208	195	267	220	237
		45	215	186	206	195	194	203	303	246	341
		46	310	294	313	257	254	274	321	355	382
		47	168	179	154	210	210	180	211	198	229
		48	133	129	128	116	117	111	147	165	183

Mean Reaction Time Left Hand

Directed Presentation		Tone			Complex Tone			Language		
	EARS	Left	Right	Both	Left	Right	Both	Left	Right	Both
No Report	Ss 01	169	183	169	162	145	138	140	143	196
	02	146	158	145	126	135	137	131	135	191
	03	173	154	172	145	173	139	170	134	145
	04	150	135	123	130	159	138	139	139	171
	05	165	166	172	191	203	214	199	189	225
	06	176	171	177	197	189	200	253	223	255
	07	152	149	139	205	214	193	191	170	230
	08	143	144	123	137	146	126	156	158	173
	09	184	165	171	166	184	184	244	243	178
	10	179	157	150	186	192	177	141	150	166
	11	162	160	153	186	180	170	185	150	188
	12	132	135	116	146	142	128	133	173	194
Report	13	125	160	153	145	156	141	157	178	194
	14	136	163	136	179	144	139	167	168	206
	15	174	152	155	161	173	154	235	240	262
	16	160	148	153	146	146	143	152	171	192
	17	147	157	150	174	167	159	183	137	190
	18	163	146	156	148	145	149	127	148	130
	19	248	200	228	247	282	285	241	289	241
	20	399	346	403	427	393	412	431	608	499
	21	238	252	213	244	238	251	341	296	348
	22	292	331	299	298	391	282	376	442	443
	23	268	259	282	271	298	331	321	347	417
	24	187	197	183	214	203	225	365	387	380

Mean Reaction Time Left Hand

Random Presentation	EARS	Tone			Complex Tone			Language		
		Left	Right	Both	Left	Right	Both	Left	Right	Both
No Report	Ss 25	182	179	168	163	162	166	163	131	146
	26	200	201	205	154	194	192	118	145	229
	27	131	135	148	116	125	120	144	129	138
	28	174	198	180	148	162	159	141	226	152
	29	148	148	142	195	195	238	141	123	188
	30	176	197	173	236	229	245	145	178	171
	31	186	184	203	262	227	209	205	159	172
	32	184	204	180	242	220	217	238	288	355
	33	140	138	134	138	141	145	164	148	222
	34	221	247	205	292	248	226	199	213	244
	35	139	136	147	163	175	172	245	170	199
	36	248	236	232	224	228	240	354	331	426
Report	37	201	185	183	168	165	134	152	132	177
	38	136	155	150	198	178	216	352	405	420
	39	178	154	204	181	150	143	192	132	171
	40	125	134	122	124	125	110	112	147	137
	41	132	128	131	146	166	146	193	147	169
	42	189	217	194	181	184	188	152	217	212
	43	224	233	219	195	340	356	379	341	411
	44	212	201	193	226	234	243	200	261	253
	45	203	244	228	194	199	196	367	333	396
	46	274	287	275	236	226	225	460	446	511
	47	172	162	163	205	209	199	300	242	242
	48	114	117	114	127	131	115	198	211	267

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