THE BRAIN AND DICHOTIC SPEECH PERCEPTION

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INTRODUCTION

The human brain is both functionally and anatomically asymmetrical, the left hemisphere being specialized for speech and language (Penfield and Roberts, 1959; Kimura, 1961; Geschwind and Levitsky, 1968; Studdert-Kennedy and Shankweiler, 1970). The tendency for the left hemisphere to be dominant for language is validated by the intracarotid injection of Amytal (Wada and Rasmussen, 1960); after injection, subjects are asked to perform speech tasks such as counting while they touch their thumb to each of their fingers. As hemiparesis develops in either the right or left hand, the diagnostician notes whether speech performance deteriorates in association with the hemiparesis. Right hemiparesis with speech involvement, of course, links the left hemisphere with speech and language function. This is the common result in most subjects whether they are right- or left-handed.

Kimura (1961) has reported a test which involves no risk to the patient and yet correlates almost completely with the results of the intracarotid Amytal test. This test involves dichotic stimulation of both ears simultaneously. One message is sent to the left ear and a different message to the right ear; both messages are usually speech, and the subject is asked to report what he has heard.

In our tests, competing nonsense syllables are used in the following manner: "ba" is presented to the right ear, "ta" is presented to the left ear, both at the same time. The patient is asked to repeat what he heard. The message to the ear ipsilateral to the lesion is usually reported accurately,

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The work on which the conference presentation was based has since been published in three parts. One part has appeared in the Journal of the Acoustical Society of America, one part in the AMA Archives of Otolaryngology, and one part is to appear in the IEEE general publication in 1973. All the work addresses itself to the question of how the normal and abnormal brain processes competing, phonetically similar messages. The illustrations and text are reproduced with the permission of the journals involved. The text is taken almost completely from these three papers and presented here in only slightly modified form.

the one to the contralateral ear is either not perceived at all, or is distorted. Thus, if the "ba" goes to the right ear of a patient with a right temporal lobectomy, he will report "ba" and miss the "ta."

Our results (Berlin, Lowe-Bell, Cullen, Thompson, and Loovis, 1972a) and the results of others (Studdert-Kennedy and Shankweiler, 1970) show the following findings for normals performing dichotic listening tasks:

1. Messages to right ears are generally more accurately reported.

2. When the messages are staggered between 30 and 90 msecs, it is the lagging rather than the leading message that is better perceived.

We wish to report the results of dichotic testing on four patients with known temporal lobe lesions, and contrast their performance to that of normals.

DATA COLLECTION TECHNIQUE

Before dichotic testing was begun, all subjects received pure tone and speech audiometric tests. Only subjects with normal monaural functions were used. The subjects always had monaural practice listening to the six syllables (pa, ta, ka, ba, da, and ga), and achieved virtually 100% scores for single monaural presentations before the competing tests were begun.

Suprathreshold dichotic tests were then given at a level equivalent to a 78dB SPL 1 kHz tone. The patient was instructed that these same syllables would be repeated but that he would now receive two syllables simultaneously, a different syllable to each ear. If he remembered both syllables, he was to check off two responses on his multiple choice answer sheet; but, if he perceived just one syllable, he was still to mark the appropriate space. Stimuli were presented first simultaneously and then separated by 15, 30, 60, and 90 msecs (and, in Experiment 2, out to 500 msecs). Each ear was given comparable lists so that lead and lag scores at all time conditions were obtained. Figure 1 shows our data from normals in the two experiments. This figure should be used as a reference for interpretation of patient data.

REPORT OF CASES

Case 1: Left Temporal Lobe Gunshot Wound

This 22-year-old college junior sustained a left temporal lobe gunshot wound. Prior to surgery, X-rays were taken which

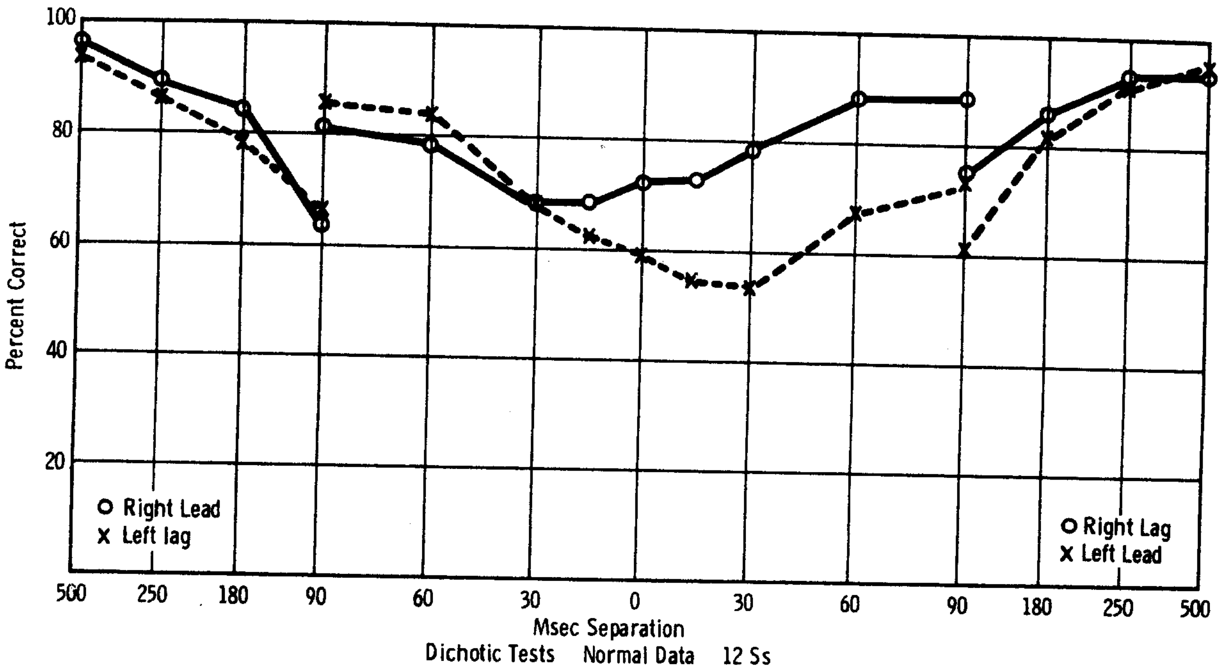

FIGURE 1. Dichotic normal lead/lag data: Experiment 1, 0 to 90 msec (N=12); Experiment 2, 90 to 500 msec (N=12).

revealed a compound depressed skull fracture in the left temporal area with extension of the missile into both the left posterior parietal and occipital regions. An emergency craniotomy was performed with debridement. A subgaleal hematoma was removed, and portions of the degenerated and contused superior and middle temporal gyri were suctioned away (Figure 2). He tolerated the procedures well. Post-operatively his neurologic status was good with no paresis.

The patient was first seen for dichotic testing in our laboratory two months posttrauma, and has been followed for over one year. Pure tone tests revealed normal hearing bilaterally; speech reception thresholds and speech discrimination scores were normal for both ears. His dichotic data clearly demonstrate how this type of testing can reveal the cortical functional asymmetry of patients with temporal lobe lesions. Figure 3 shows his asymmetric ear scores in dichotic tests. Note both the normal left ear function and the extremely depressed right ear scores.

Longitudinal studies appear to reflect an interesting change in temporal lobe function. Whereas his left ear scores are normal two months posttrauma, retest data (Figure 4) show a significant improvement in left ear scores and a concurrent slight decrease in the right ear function. His left ear (reflecting right temporal lobe function) is performing at a level above that of <u>normals' right ears</u> in dichotic tasks.

<u>Case 2</u>: <u>Left Temporal Lobectomy Seizure</u>

This 16 year-old patient with left temporal lobe epilepsy had her first seizure at age one, and, after age six, started having regular generalized seizures, which increased in frequency as she reached menarche. Her seizures of two to three minutes duration were characterized by a short period of loquaciousness prior to the seizure, followed by cessation of speaking and understanding, reduction of sensation of the right arm, quivering of the lips, and an aura of "fright." The patient would then lose consciousness, and, during this period, tonic-clonic movements of her extremities could be observed.

When drugs were ineffective in controlling seizure activity, she was readmitted to the hospital for a complete neurological work-up. The results of brain scan and pneumoencephalogram were normal, but electroencephalograms consistently showed a left temporal lobe epileptogenic focus. The diagnosis of left temporal lobe epilepsy was made on the basis of the EEG's, history, type of seizure, X-ray evidence of asymmetry of the cranium, and psychological abnormalities. There was no recognizable aphasia or apraxia.

Patient 1
Left Temporal Lobe Gunshot Wound

No major hippocampal resection

FIGURE 2. Schematic of surgical resection: Patient 1, left temporal lobe gunshot wound.

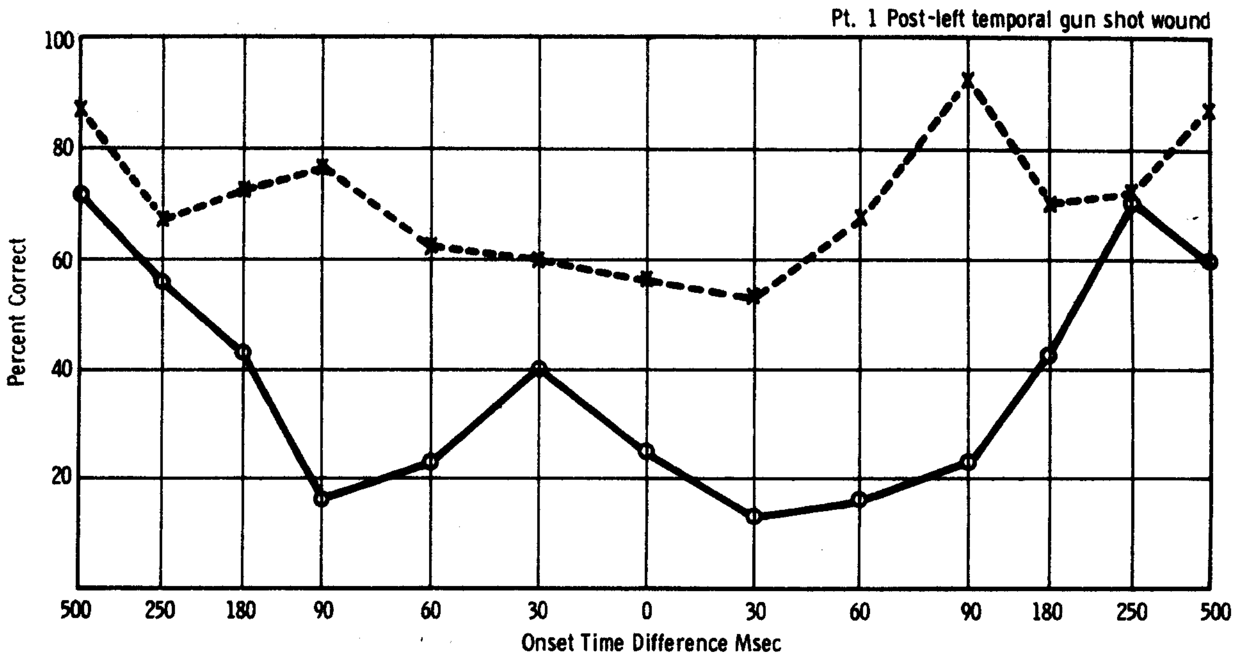

FIGURE 3. Dichotic lead/lag data of Patient 1.

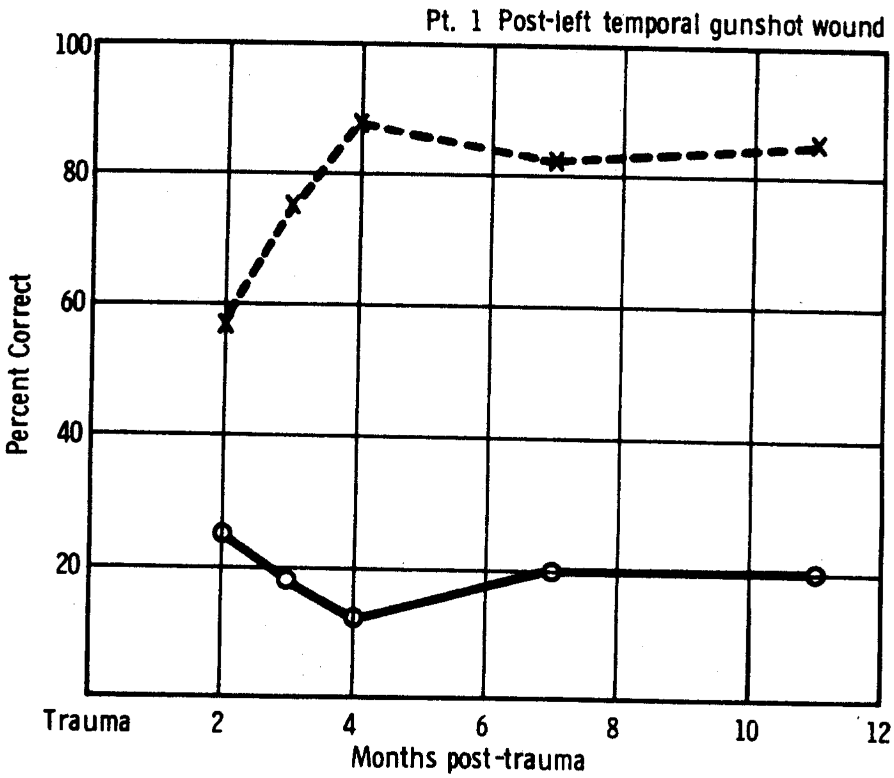

FIGURE 4. Simultaneous dichotic data from longitudinal testing of Patient 1.

Dichotic testing preoperatively revealed extremely depressed scores for both ears, with the left ear generally doing somewhat better than the right for comparable test conditions. The bilaterally depressed scores are a general finding in patients with left temporal lobe epilepsy, as the dominant hemisphere for language processing is impaired and both hemispheric inputs are thus degraded.

The surgical procedure involved excision of the anterior five to six cm of the temporal lobe with dissection down to the tentorial margin and back to the vein of Labbe (Figure 5). Pathologic examination of the excised temporal lobe showed medial temporal sclerosis.

Postoperatively, the dichotic test data showed significant changes. As seen in Figure 6, left ear scores improved and currently follow the normal curve, while right ear scores flattened out and are generally depressed.

Case 3: Right temporal Lobectomy

This patient had a history of seizures with a diagnosis of epilepsy since age 4. The progressive temporal lobe syndrome showed a predominant right-sided focus, although EEG abnormalities did suggest some left temporal lobe dysfunction which might have been a mirror focus. There was never a significant postictal element of aphasia or language dysfunction. His psychomotor seizures showed a classic picture of loss of consciousness, falling to the floor associated with tonic-clonic movements, and occasionally urinary incontinence and tongue-biting. These attacks, of three to five minutes duration, were usually followed by postictal drowsiness. Since his condition was intractible to medical therapy, right temporal lobectomy was performed at age 29.

Resection of the right temporal lobe was carried out 6 1/2 cm back from the tip of the temporal lobe to the vein of Labbe. Figure 7 illustrates the surgical result, and indicates that the anterior portion (2 1/2 cm) of the hippocampus was sacrificed in resection of the specimen and suctioning of the area.

Postoperative audiological work-up showed bilaterally normal hearing and normal SRT and discrimination scores. Since our current battery of dichotic tests had not been completed prior to this patient's surgery, no comparison of preoperative and postoperative scores could be made; however, the postoperative scores are consistent with those of other patients we have seen. Figure 8 illustrates the usual depression of contralateral ear scores, while the ear ipsilateral to the lesion performs within normal limits. The left ear scores show improvement only when messages are separated by 180 to

Patient 2
Left Temporal Lobectomy

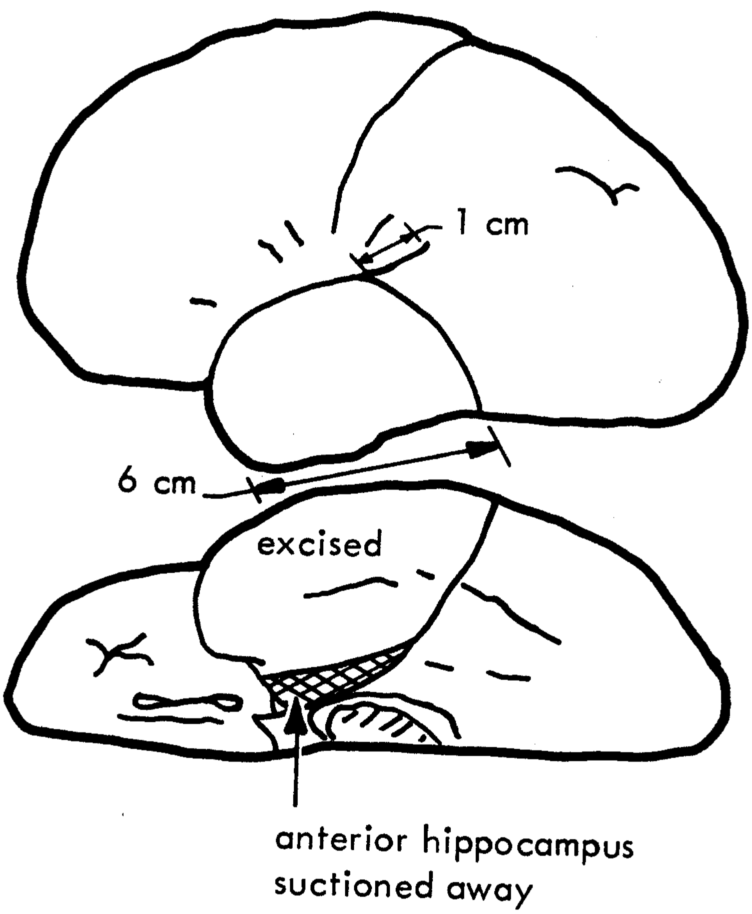

FIGURE 5. Schematic of surgical resection: Patient 2, left temporal lobectomy seizure.

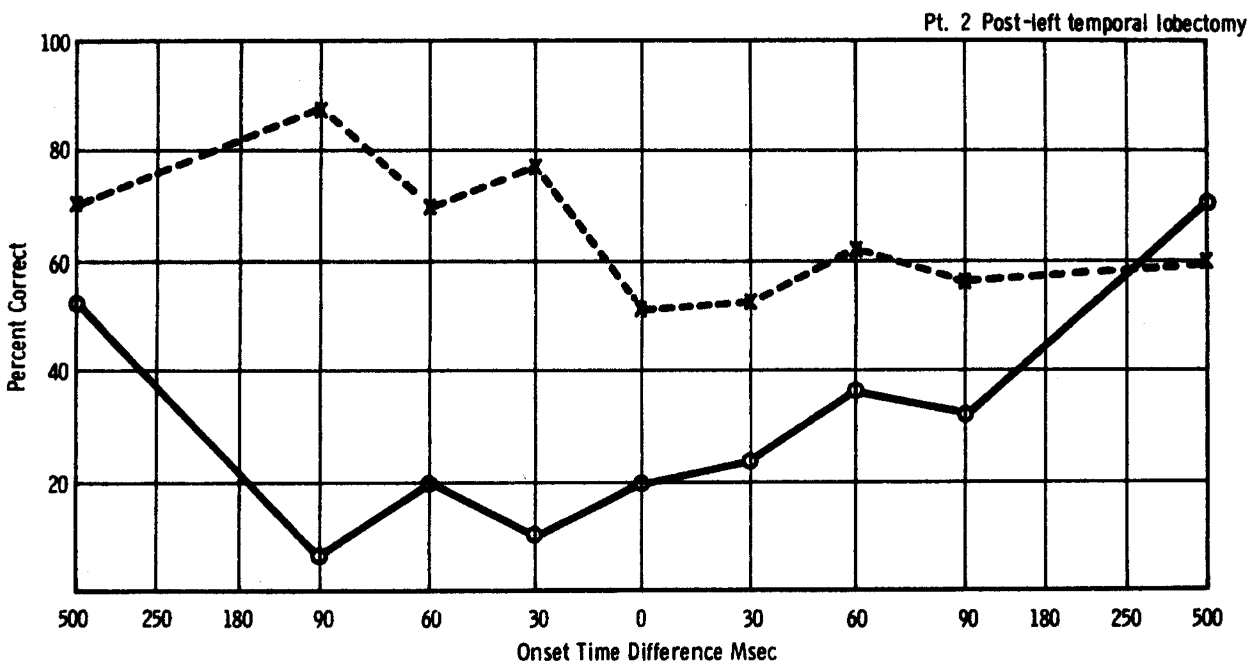

FIGURE 6. Postoperative dichotic lead/lag data of Patient 2.

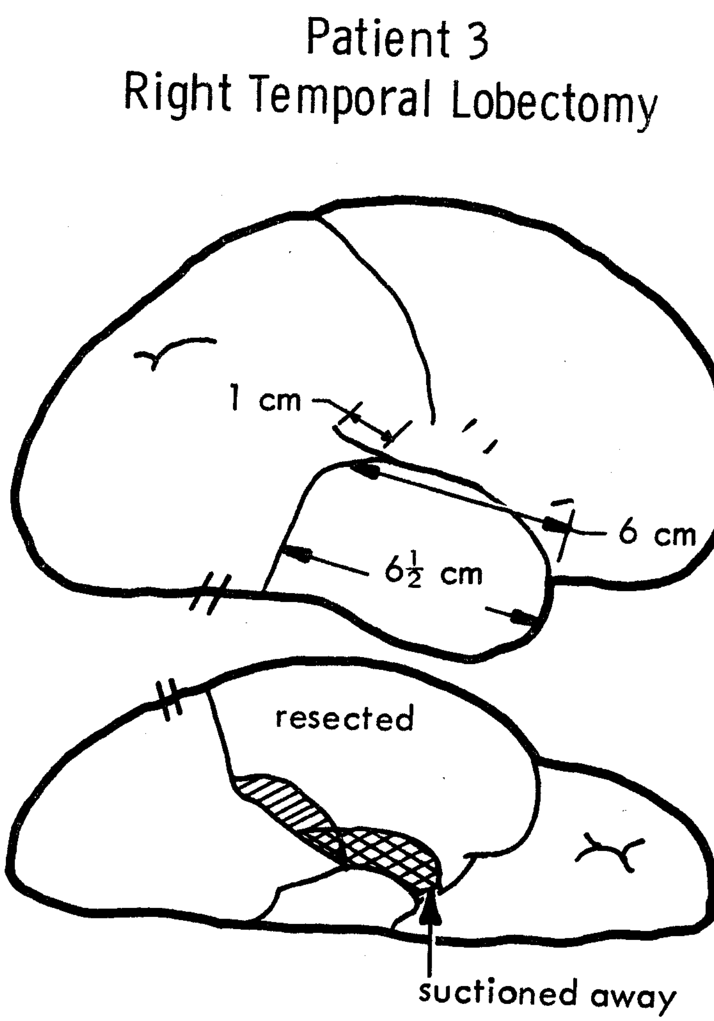

FIGURE 7. Schematic of surgical resection: Patient 3, right temporal lobectomy seizure.

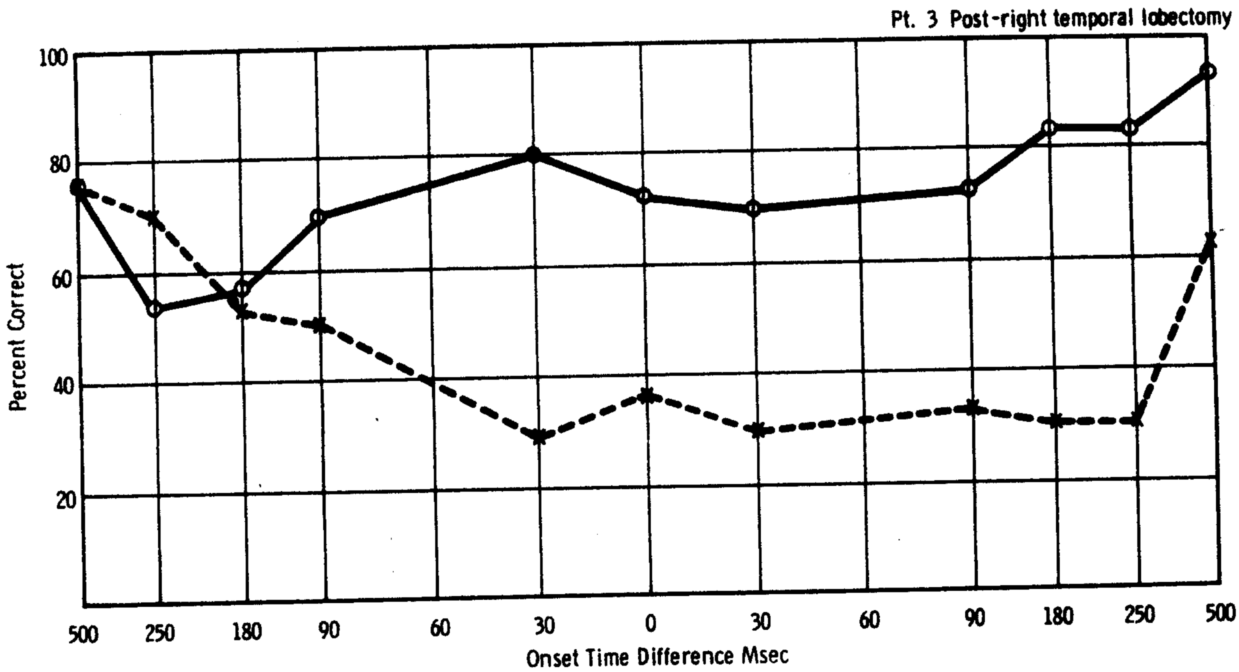

FIGURE 8. Postoperative dichotic lead/lag data of Patient 3.

500 msecs and the left ear has the advantage of receiving the lagging stimulus. Under all other listening conditions, there was a significantly better report from the right ear.

Case 4: Right Temporal Lobectomy

This patient had an eight-year history of seizure disorder related to calcification of the right basal ganglia which had been confirmed by X-ray studies. His seizures were characterized by an asymptomatic preictal period followed by sudden loss of consciousness. There was lip-smacking but no gross motor components during his seizures, and he would become lucid fairly rapidly, postictally. An abnormal EEG revealed right temporal and central spikes with diffuse slowing. The positive spikes were taken as evidence of paroxysmal subcortical discharges, arising in the hypothalamic region. The results of other clinical tests, such as echoencephalography and brain scan, were normal.

Dichotic preoperative tests showed a marked laterality effect with the left ear performing very poorly in comparison with the right. Figure 9 illustrates poor scores in the left ear for simultaneous as well as time-separated tests of 30, 60, and 90 msecs.

The patient was taken to surgery and a right temporal craniotomy and complete temporal lobectomy was performed (Figure 10). The hippocampal region was also removed. The diagnosis of oligodendroglioma of the right temporal lobe was determined from a frozen section.

Two weeks postoperatively, dichotic tests were repeated with little change in function, although a slight improvement in the right ear scores was noted. Eight weeks postoperatively, the change was again minimal, but in the direction of a slightly improved right ear report.

COMMENT

It is clear from these data that the advantage which normal listeners achieve when they hear a lagging message in a pair is lost to patients with temporal lobe lesions. If, in fact, these patients suffered an impairment of short-term memory, we would guess that the intelligibility of the lagging message would be not only better but continue to improve as the separations between the words became larger. Such an arrangement would demand less retention capability on the part of the patient, and therefore, the last word "in" would be the first word "out." This happened in neither the normals (between 180 and 500 msecs) nor the patients with temporal lobe lesions at any time separation. The patients, however, show what we feel is a distinct failure to perceive messages

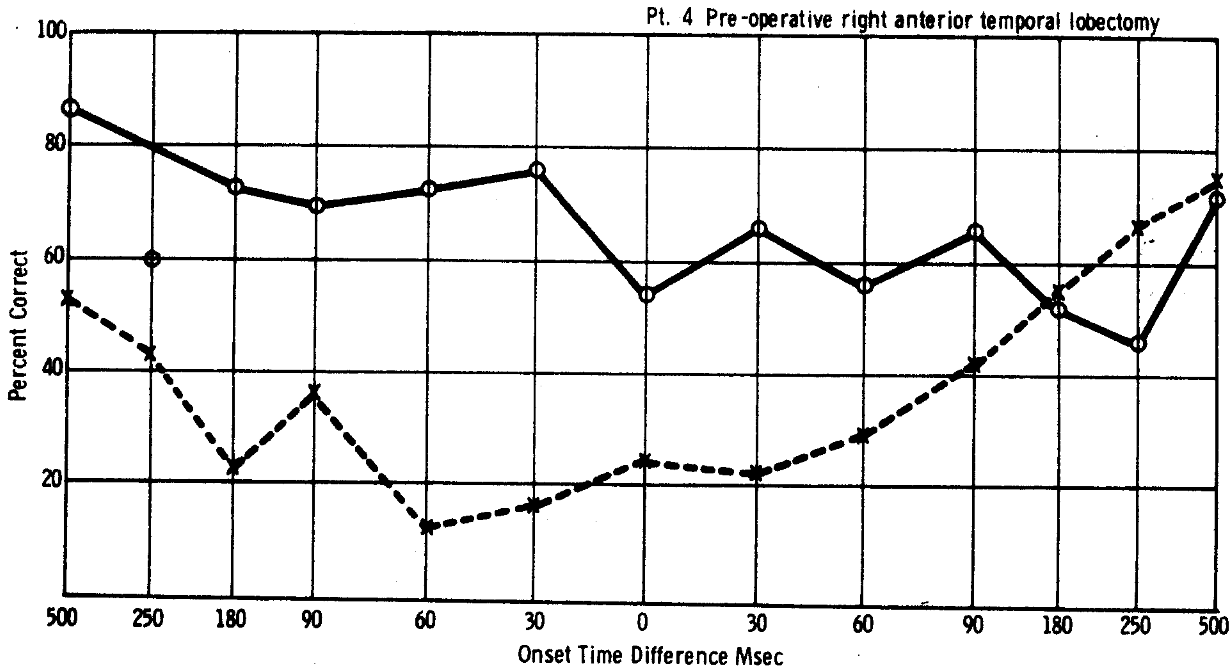

FIGURE 9. Preoperative dichotic lead/lag data of Patient 4, right temporal lobectomy seizure.

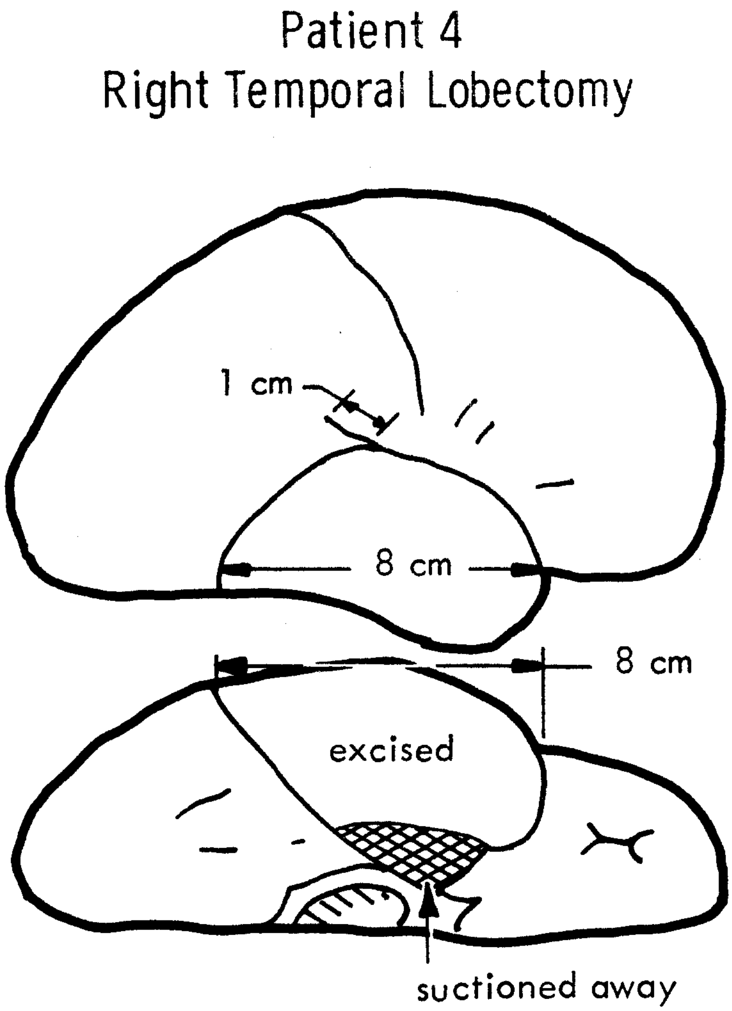

FIGURE 10. Schematic of surgical resection (case 4.)

accurately in the ear contralateral to the lesion, independent of the temporal sequence of the words.

The relationship of temporal lobe functions to perception of temporal sequence has been well documented (Efron, 1963a; Efron, 1963b; Jerger, Weikers, Sharbrough, and Jerger, 1969; Berlin and Lowe, 1972). It seems to us, on the basis of our data, however, that some preliminary acoustic analysis capability has also been lost following temporal lobe lesion, and that our findings cannot be explained entirely on the basis of the patient's inability to appreciate a temporal sequence (Efron, 1963b). We believe that both the right and left anterior temporal lobes must participate in some type of preliminary speech information processing; otherwise there would be no postoperative laterality effects following temporal lobe lesions. Such patients generally show an almost complete suppression of dichotic speech information sent to their contralateral ears; such a finding has been reported in patients with corpus callosum sections (Milner, Taylor, and Sperry, 1968; Sparks, Goodglass, and Nickel, 1970), and we have seen it in a patient with a total right hemispherectomy. This suggests to us that the anterior temporal lobes play a critical role in either preliminary speech analysis or in the relay of speech information to the posterior temporal cortex via association pathways. We also hypothesize that information coming from the right anterior temporal lobe to the left posterior temporal areas need not pass through the left anterior temporal areas; as a matter of fact, if such a serial relationship existed, then a left anterior temporal lobectomy would have devastating results on all speech and hearing functions. On the contrary, it is only left posterior temporal-parietal removals that have such serious effects.

Sparks et al. (1970) have proposed a model which our own data support. The consistent contralateral ear deficit, which they called "extinction," was seen primarily in their surgical cases but not in their vascular cases. They suggest that if deep, left hemisphere lesions interfere with connections from the right to the left temporal lobe, one might also see ipsilateral "extinction" in the left ear with a left hemisphere lesion. These ideas are consistent with a basic speech processor, which seems to identify and classify speech as a unique signal, and uses portions of the left hemisphere to perform its final speech classification function.

The question then arises, how unique is speech as a stimulus? Unique changes in the patients' dichotic listening scores for the ear contralateral to the temporal lobe lesion "signal" that speech elements have been recognized in the ipsilateral ear. This "signal" is a score reduction of the contralateral ear; little reduction occurs when noise is introduced to the ipsilateral ear.

Figure 11 shows what happened when 11 normal subjects were given dichotic listening tasks, with intensity differences deliberately generated between ears. One ear received syllables at a reference level (80dB SPL re 1 kHz tone), and the other ear's signal was attenuated by as much as 50dB. The figure shows that, as the intensity is varied in one or the other ear, there is a gradual increase in scores for the unattenuated ear and a reciprocal decrease in scores for the attenuated ear out to approximately 20dB. Beyond this point, the unattenuated ear improves sharply, reaching 100%, while the attenuated ear drops to near chance (20%) levels for a 50dB difference between ears. The expected right ear superiority is seen for the equal intensity condition and is maintained as the right ear is attenuated as much as 10dB.

Now let us look at three patients subjected to a similar experimental model. Two had anterior left temporal lobectomies, the third an anterior right temporal lobectomy; however, all three show remarkably similar results.

The patients were first given dichotic speech tasks with the two ears at equal intensities. For all three, the expected poor contralateral ear score was observed. Figures 12, 13, and 14 show that as the intensity of the ipsilateral ear increased in the dichotic task, the intelligibility function of the contralateral ear dropped almost reciprocally. However, when the signal in the ipsilateral ear was <u>noise</u> instead of speech, much less of a decrement was seen in the contralateral ear. This effect, and the consistent small crossing and recrossing seen when the ipsilateral ear received signals between 12 and 20dB re SRT was consistent for all three patients. Figure 15 summarizes the effects on the contralateral ear of noise or speech in the ipsilateral ear.

The contralateral* ear in this experiment was evidently signaling the presence of speech in the ipsilateral ear by a gradual decrement of its articulation score as the speech elements in the ipsilateral** ear became more and more intense.

Now then, other stimuli had to be used to study suppression. Let us review our rationale for the use of these other signals.

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*To be called henceforth the "weak ear," also representing the <u>left</u> ear for normals.

**To be called henceforth the "strong ear," also representing the <u>right</u> ear for normals.

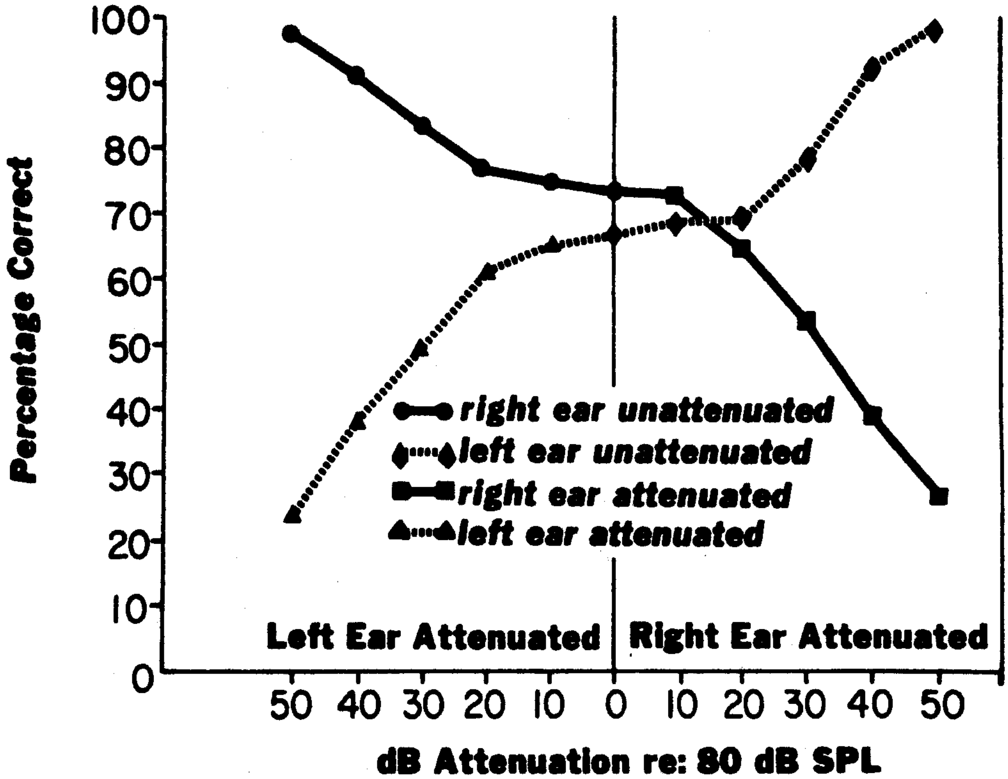

FIGURE 11. Percentage of correct responses to dichotic pairs with right or left ear attenuated--normal data (N=11).

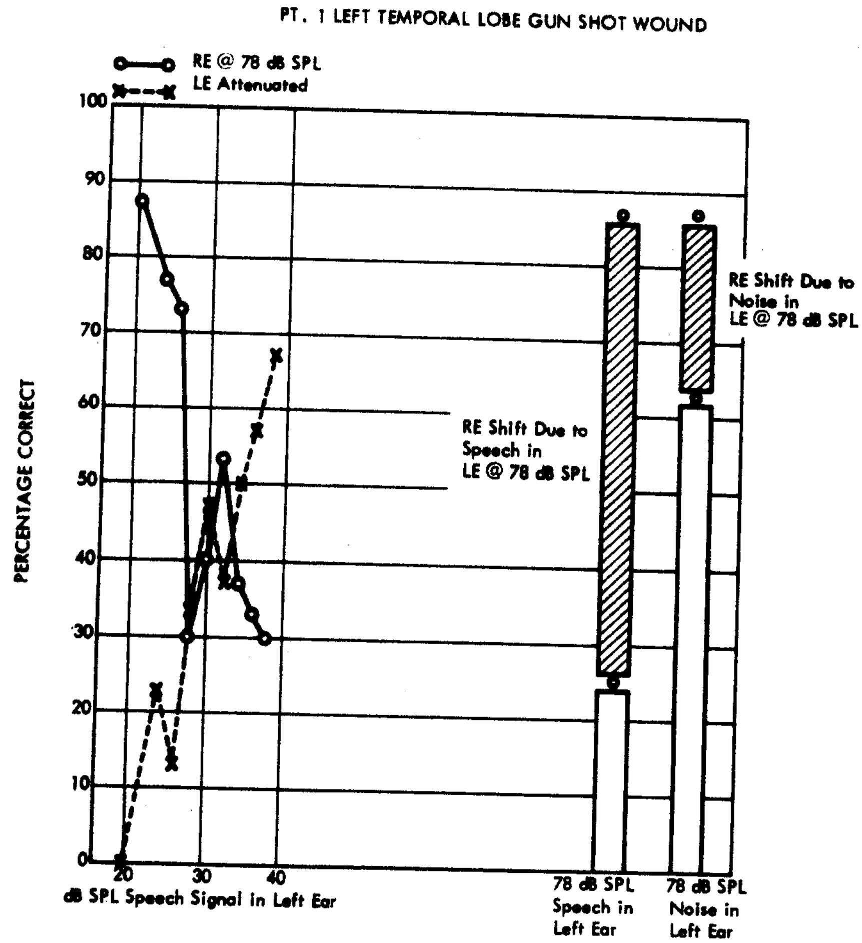

FIGURE 12. Patient 1. Left temporal lobe gunshot wound.

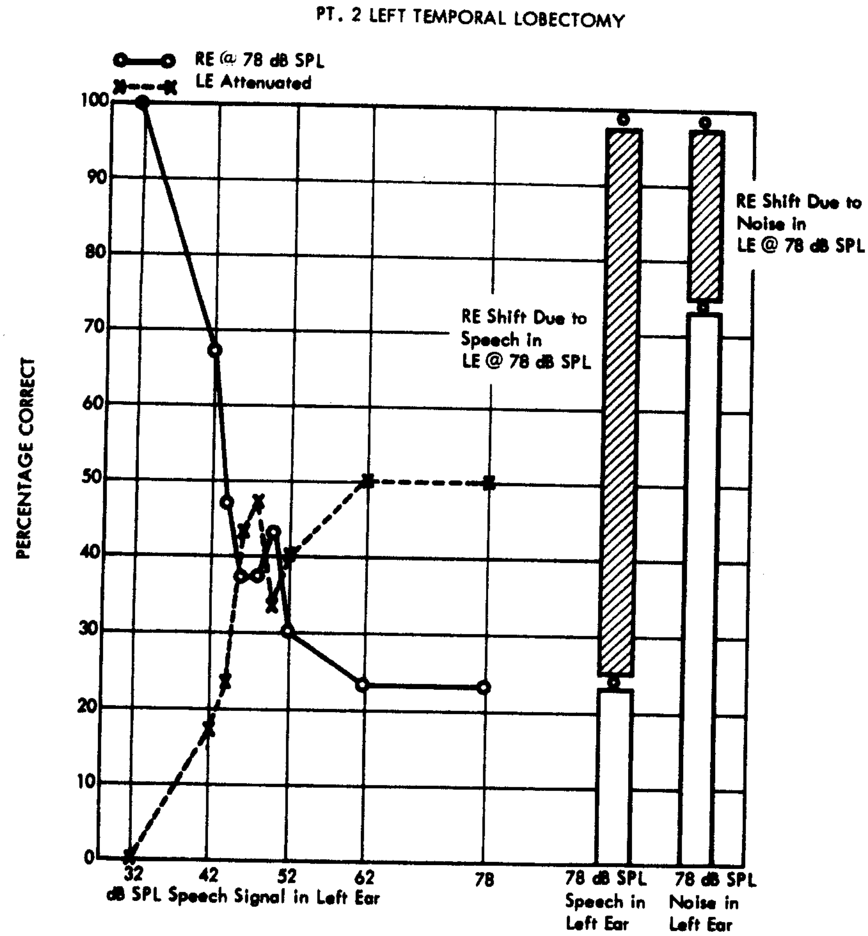

FIGURE 13. Patient 2. Left temporal lobectomy.

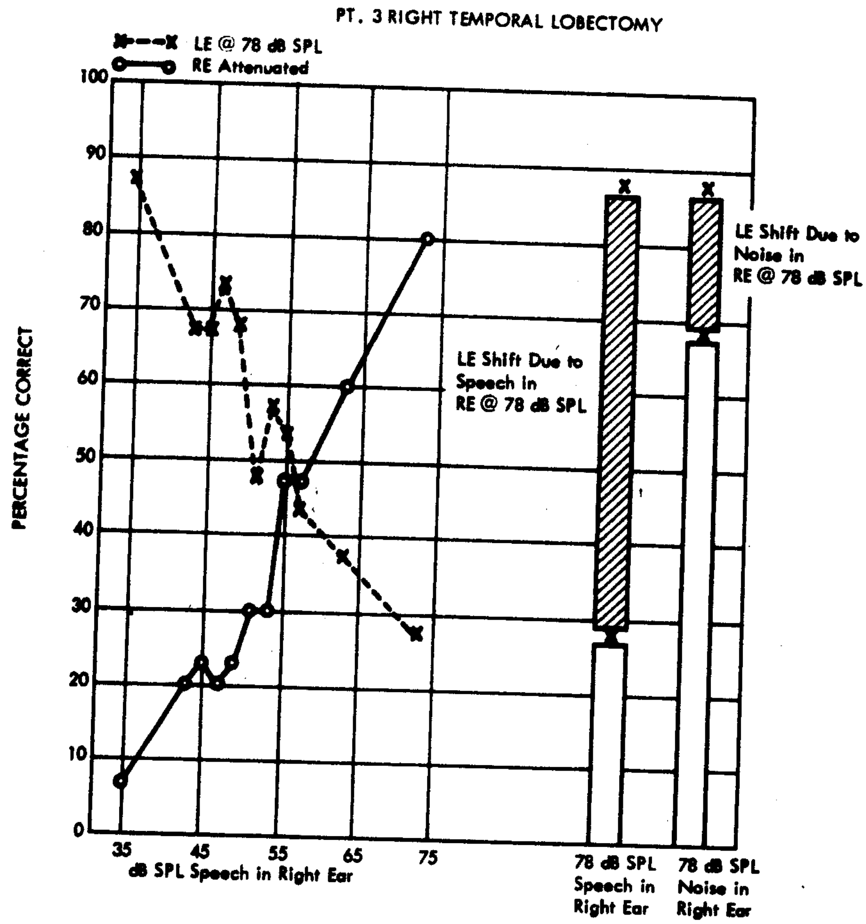

FIGURE 14. Patient 3. Right temporal lobectomy.

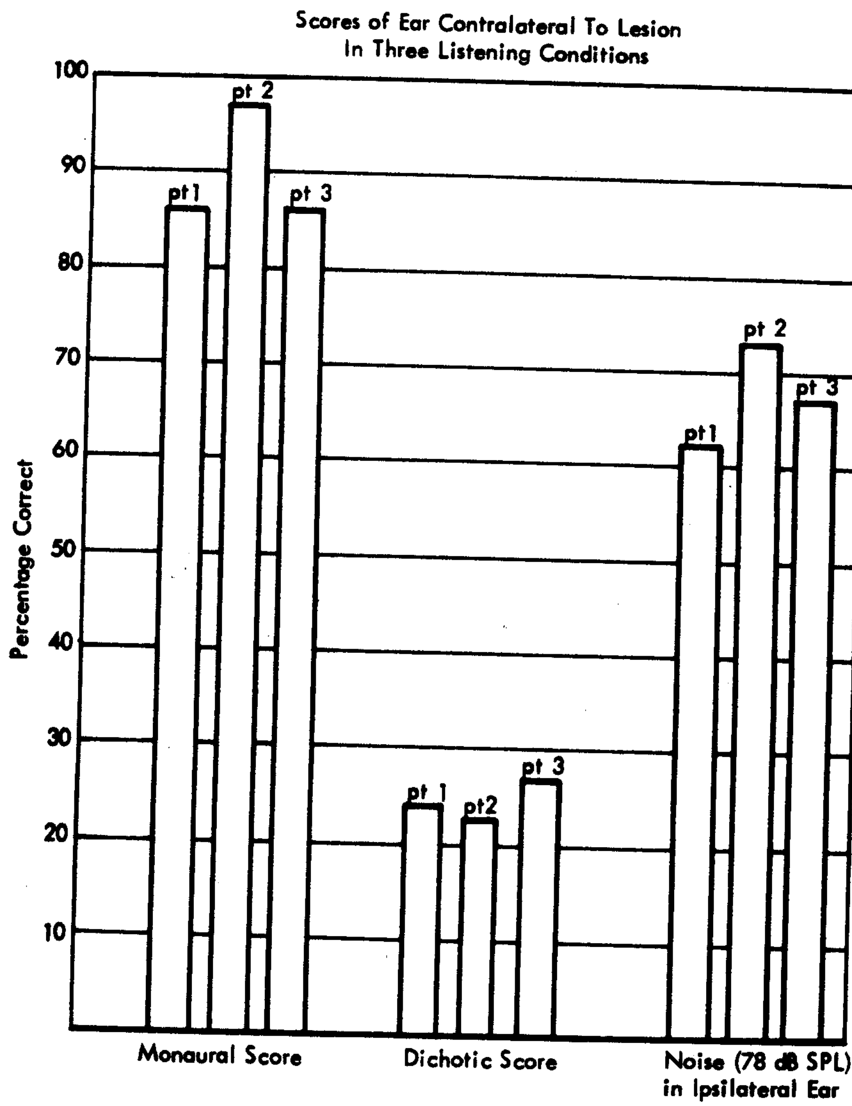

FIGURE 15. Scores of ear contralateral to lesion as a function of ipsilateral ear message. Monaural scores and dichotic scores are for the contralateral ear only.

METHOD

Normal Subjects

Six volunteers who displayed left-ear deficits in a standard dichotic listening test[1] served as normal Ss. Four Ss, two of whom were females, were recruited from the laboratory staff and were generally familiar with dichotic listening procedures[2]. The two additional Ss, one of whom was female, were undergraduate students in Louisiana State University in New Orleans. All Ss were right-handed, had audiometrically normal hearing, and were native speakers of American English.

Patient Subjects

Temporal Lobectomees

Four patients with left anterior temporal lobectomies and two patients with right anterior temporal lobectomies were used. All had normal hearing and normal speech and language. All showed good monaural CV identification scores for both ears.

Hemispherectomees

One left and two right hemispherectomees were studied. All had normal pure tone hearing and good CV identification scores with monaural presentation.

Stimuli and Tapes

The six stop-vowel syllables [ba], [da[, [ga], [pa], [ta], and [ka] served as CV stimuli. Each of these CV's was naturally produced and recorded on tape. Dichotic pairs of the stimuli were re-recorded on a two-channel tape with onsets aligned using a mechanical delay line. Six dichotic CV tapes were produced. Each tape consisted of a random series of the 15 possible dichotic pairs, each pair appearing twice, for a total of 30 trials. These tapes were used in the CV-CV condition.

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[1]This test was a 30-trial dichotic CV test presented at 75dB SPL. Subjects were discarded if they displayed a right-ear deficit on this test.

[2]Comparison of these experienced Ss' data with naive listeners' data revealed no substantial differences in effects.

REVIEW OF RATIONALE FOR THE EXPERIMENTS

1. In monaural listening, the CV's are generally intelligible regardless of the ear to which they are presented (for both patients and normals).

2. Our previous experiment showed that with a CV in the weak ear and continuous white noise in the other, CV identification scores were nearly as good as monaural scores.

3. When a CV instead of noise is presented to the strong ear, however, we saw a marked drop in the identification score for the CV simultaneously presented to the weak ear. These different effects observed for CV's and noise lead to the following question:

   Does the degree of suppression of weak-ear scores depend on whether the signals to the strong-ear possess speech-like properties?

4. This general question leads to an experimental one:

   What other signals with acoustic features sampling the range from speech to noise will suppress weak-ear performance?

5. The present experiment attempts to obtain a partial answer as follows:

   a. A CV of constant intensity was always the stimulus to the weak ear.
   b. "Challenges" with different degrees of acoustic similarity to CV's were simultaneously presented to the strong ear.

6. If the strong-ear challenge were acoustically similar to a CV, we reasoned that the detection of its special speech-like acoustic features would elicit suppression of the weak-ear score. If, on the other hand, little or no effect were to be seen, we would reason that acoustic similarity to speech is not in and of itself a sufficient condition for demonstrating weak-ear suppression.

The "bleats" were acoustically isolated second and third formants of the three-formant synthetic CV's [ba], [da], [ga], [pa], [ta], and [ka]. These bleats were paired with the natural CV's to produce two 30-trial dichotic tapes. No CV was paired with a bleat derived from the same CV. These CV-bleat tapes were constructed in a similar manner to that used for the CV-CV tapes except that a computer controlled PCM system at Haskins Laboratories was used to produce aligned pairs (Cooper and Mattingly, 1969).

One 30-trial CV-vowel tape was prepared by re-recording one channel of one of the CV-CV tapes and electronically replacing the CV on the other channel by a natural vowel [a]. The vowel was automatically envelope-shaped to follow the amplitude envelope of the CV it replaced.

PROCEDURE

Subjects were run in groups of one to four. Each group participated in a single two-hour session. Before dichotic testing Ss received practice in monaural listening to the six CV's during which they displayed adequate discrimination.

The dichotic testing session was divided into three periods. During each period Ss heard only one type of stimulus pairing (CV-CV, CV-bleat, or CV-vowel). The order of presentation of stimulus types was randomly determined for each group of subjects. During any single period the Ss were presented with five 30-trial dichotic tests. For the first test in each period, the weak-ear CV was presented at 75dB SPL and the strong-ear stimulus at 35dB SPL[3]. For each successive test, the strong-ear stimulus was increased 10dB. For the final test in a period, both stimuli were presented at 75dB SPL.

All Ss were instructed to listen to the dichotic CV-CV and CV-bleat tests and to give two different responses, guessing whenever necessary. When the vowel was presented to the strong ear, two guesses were not required.

The manner in which the intensity of the strong-ear signal was to be varied was explained to the Ss in the CV-vowel and CV-CV condition. The acoustic derivation of the

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[3]For three of the normals, and for all patients, the initial strong-ear value was 10dB above SRT. SRT in all cases was between 20 and 25dB SPL.

bleat was not explained, although Ss were instructed to attempt to identify the bleats as CV's[4].

One hemispherectomee could not participate in the CV-vowel or CV-bleat condition and one normal could not participate in the CV-CV condition.

RESULTS

Overall Effects of the Type of Challenge

Figure 16 shows how the three different challenges affect the identification of the weak-ear CV for the normals. Results for the patients are presented in Figures 17 and 18. The ordinates indicate the percent correct identification of the CV presented to the weak ear and the abscissa shows the intensity of the challenge in the strong ear[5].

For normals, the bleats and CV's tend to show greater suppressive effects than do the vowels. The patients' data are similar to normals' except for the generally increased degree of suppression. The most consistent difference is seen for the vowel. At the higher intensities, the vowel appears to have nearly the same degree of suppressive effects as the bleats and CV's.

Effects of Intensity

For both normals and patients, increases in intensity resulted in increased suppression for all three types of signals. The rate at which suppression increased with increases in intensity was not, however, the same for all

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[4]Subsequent analysis of the data indicated that most Ss could not identify the CV's from which the bleat had been derived (neither monaurally nor dichotically). Analysis of the experimental data for those few Ss who were generally successful in identifying the bleats as the appropriate stop-vowels showed no systematic departures from that obtained for the other Ss.

[5]The data in this and other figures have been adjusted for guessing. The following formula was used:

$$\text{Corrected Score} = K - E \left[\frac{P_c}{1-P_c}\right]$$

where K = percent correct
E = percent errors
P_c = probability of being correct by chance
When one response is required $P_c = 0.167$;
when two responses are required $P_c = 0.333$.

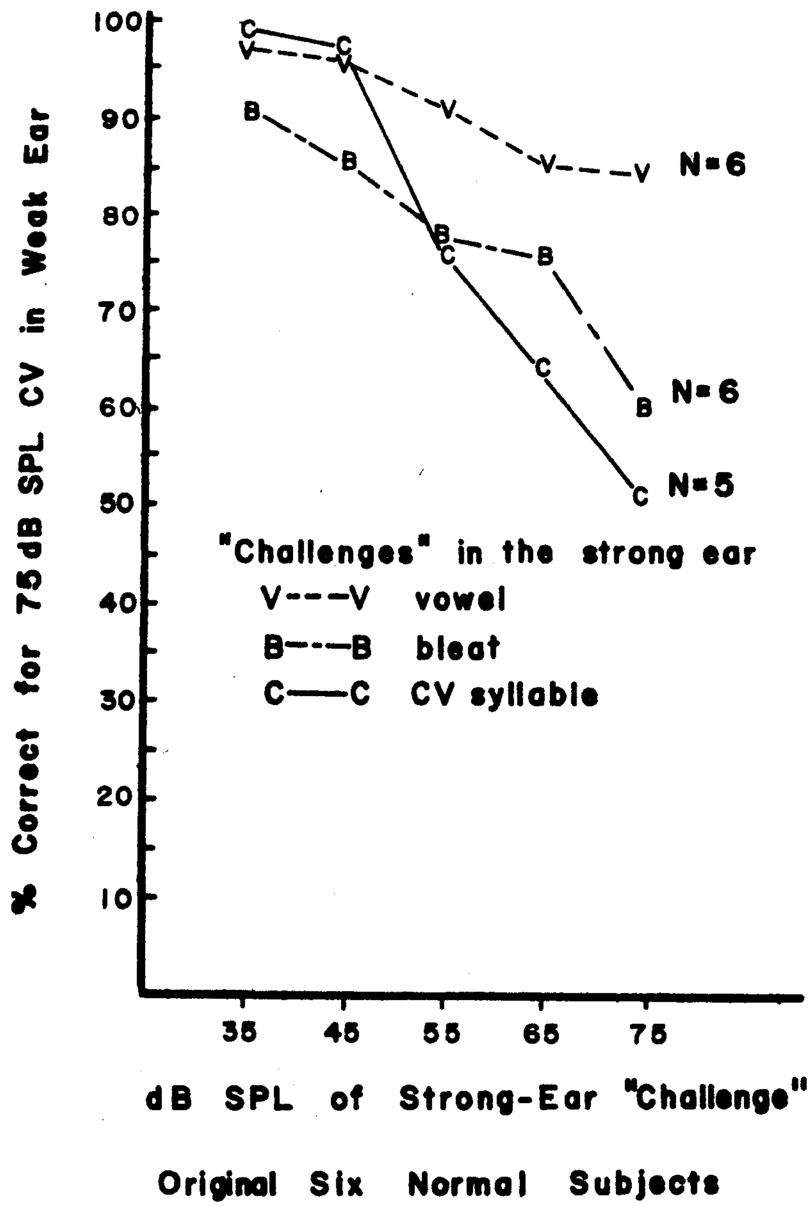

FIGURE 16. Weak-ear (left-ear) scores for the original six normals. Two responses were required for the CV and bleat conditions, one response for the vowel conditions. The data have been corrected for guessing such that zero percent correct on the ordinate reflects chance performance.

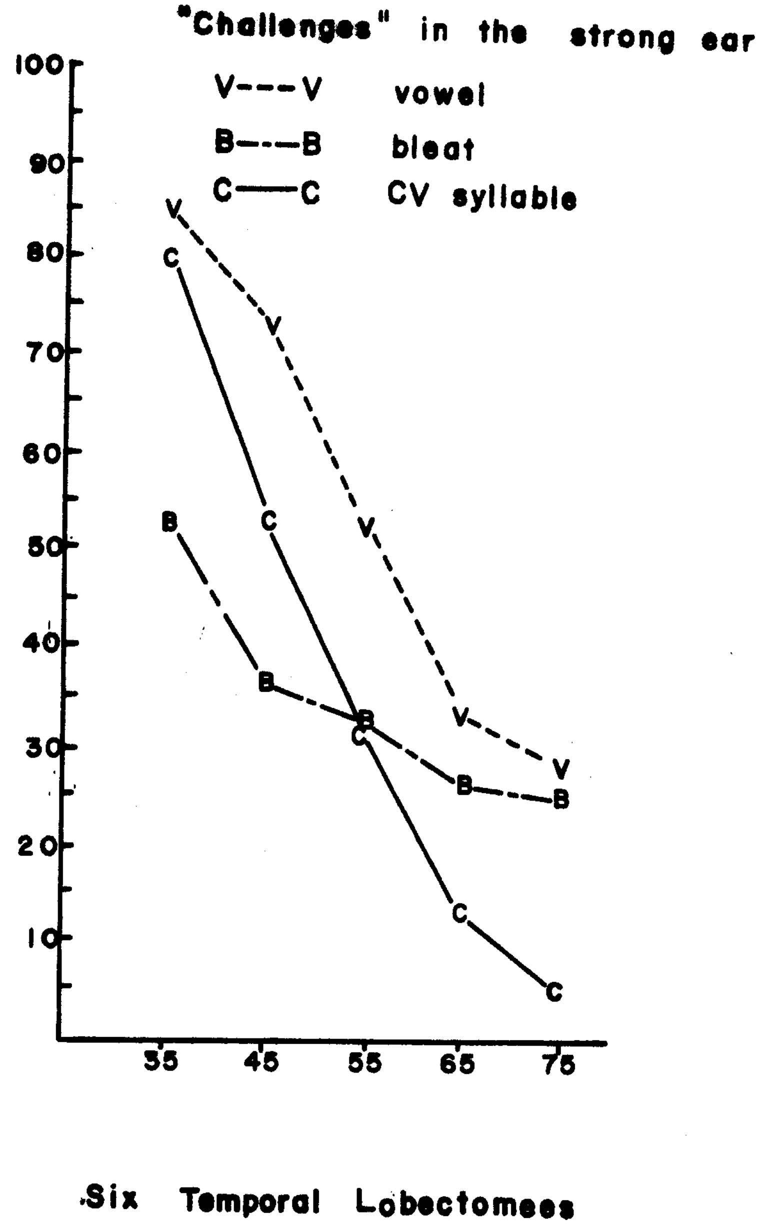

FIGURE 17. Weak-ear scores for the temporal lobectomees. Two responses were required in the CV condition. One response was required in the vowel condition. For three of these patients, one response was required in the bleat condition; for the other three patients, two responses were required. The bleat data have been combined for both types of response conditions. Corrections for guessing have been applied such that zero percent correct represents chance performance.

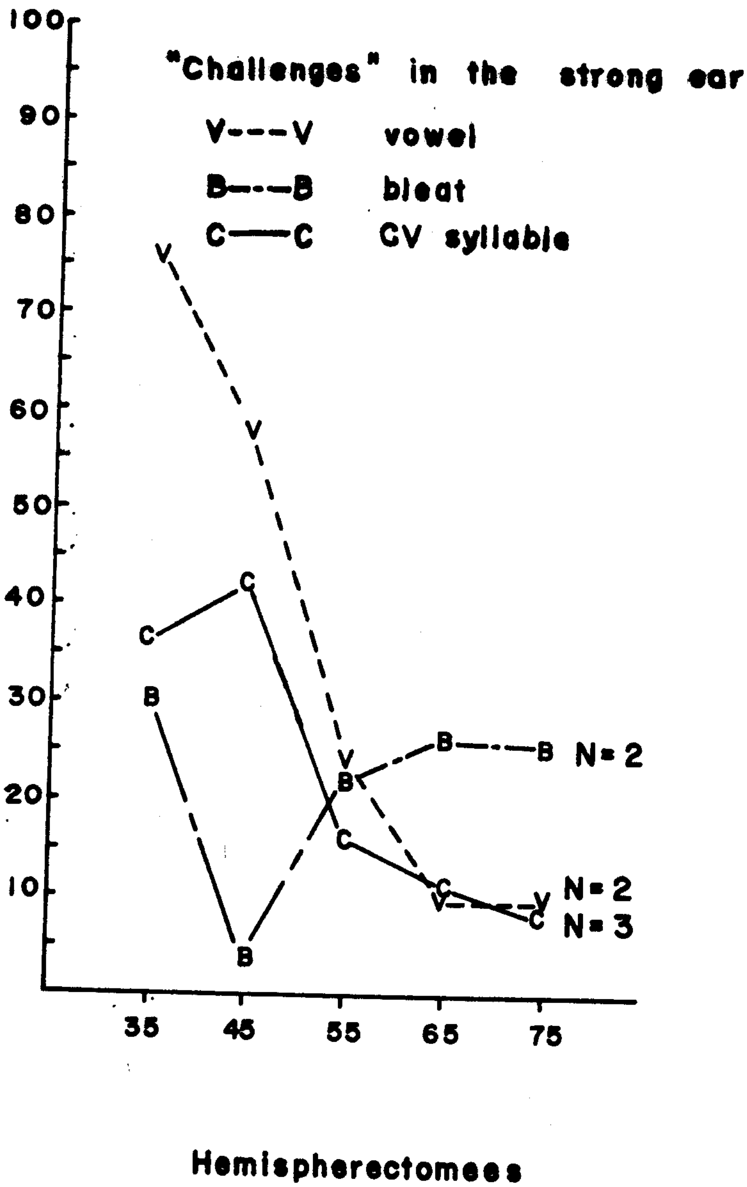

FIGURE 18. Weak-ear scores for the hemispherectomees. Two responses were required in the CV condition. One response was required in the vowel and bleat conditions. Corrections for guessing have been applied such that zero percent correct represents chance performance.

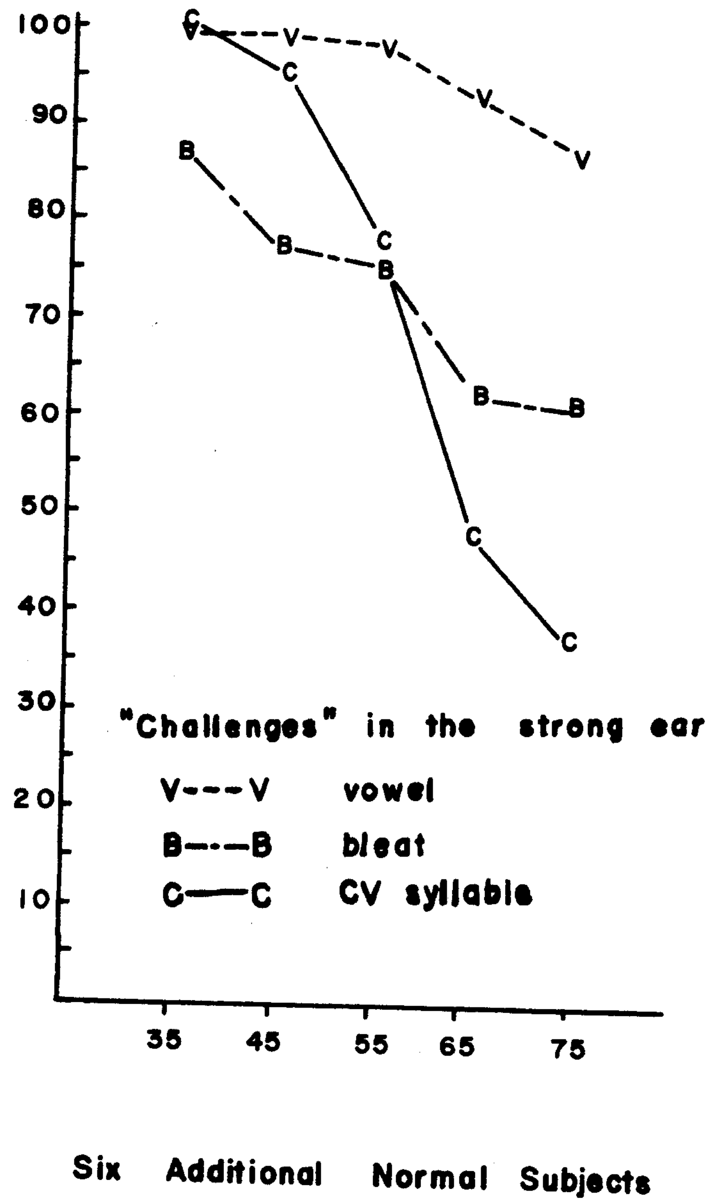

FIGURE 19. Weak-ear (left-ear) scores for the six additional normals. Subjects were instructed to attend to the weak-ear and give one response in all conditions. Corrections for guessing have been applied such that zero percent correct represents chance performance.

a. The Ss were not made aware of the repetitions of the test.
b. Examination of individual S's data did not reveal a pattern suggesting that parts of the CV sequence were remembered from one test to the next.
c. Substantially greater vowel suppression was observed with patients than with normals, suggesting that normals' high performance may be due to effects other than learning.

DISCUSSION

Development of a Model for Suppressive Effects in Normals

For normals the weak-ear deficit observed with competing bleats was nearly as great as that seen for the CV's. A similar but less dramatic pattern of suppression was observed for vowels. These observations present somewhat of an anomaly. Other dichotic experiments have shown that both vowels and bleats do not behave like CV's. For example, neither vowels nor bleats when paired dichotically display left-ear deficits as large as those seen for CV's (Shankweiler and Studdert-Kennedy, 1966; Porter, 1972; Porter, Shankweiler, and Liberman, 1969). These different effects observed for dichotic bleats, vowels, and CV's in other experiments have been interpreted as reflecting the different degree to which each type of signal requires special perceptual processing in order to reveal a phonetic message. The consonantal information in CV syllables is more encoded in the sound stream than is the phonetic information in an isolated vowel and, presumably, special perceptual processing is required to "decode" the former but is not usually required for the latter (Liberman, Cooper, Shankweiler, and Studdert-Kennedy, 1967). Non-speech sounds should never require the special phonetic processing. The relatively large left-ear deficit observed for dichotic CV syllables might, therefore, be interpreted as arising from the competition between the two signals during phonetic decoding in the left hemisphere. Since this single special processor is usually not required for vowels and rarely if ever required for non-speech, left-ear deficits for these signals are small or absent. If this interpretation is correct, then why in the present study do we find weak-ear deficits when the challenges are vowels and bleats? It is difficult to see how these two unencoded signals could provide so much "competition" during the decoding of the weak-ear CV. We would like to suggest that these signals produce their suppressive effects not because they actually "compete" with weak-ear signals during phonetic decoding but, rather, because they appear to the nervous system to be likely candidates for the special processing. More specifically, we suggest that the auditory system is particularly sensitive to the time-by-frequency acoustic patterns of signals such as speech and that the presence of such patterns in the strong-ear signal is a sufficient condition for disturbing the processing of the CV presented to the weak ear. We thus interpret weak-ear deficits to be due in part to the interaction between the signals prior to phonetic processing, at a point in processing where the acoustic features of the signals have been detected and represented in the auditory system but a point before that at which these features are further processed to yield a phonetic message. Following the terminology suggested by Studdert-Kennedy (1970) we will refer to this acoustic-feature-detection point as the _pre-phonetic_ or _auditory_ stage of processing.

Assuming that an interaction of left- and right-ear signals occurs during the auditory stage, why does the left-ear signal suffer the most? Several investigators have suggested that the left-ear deficit seen for normals reflects an imbalance in the access the two ears have to the speech processor during dichotic presentation of signals. Right-ear signals are assumed to be directly transmitted to the contralateral left-hemisphere speech processor whereas left-ear signals must travel a more indirect route, first to the contralateral right hemisphere and then across the corpus callosum to the left. It is this indirect route which, because of its length and/or inefficiency is assumed to place the left-ear signal at a disadvantage (relative to the directly transmitted right-ear signal) when it arrives for processing in the left hemisphere[6]. On the basis of the present data we would like to extend this model and suggest that before phonetic analysis begins the weak- and strong-ear signals interact in terms of the relative strength of their acoustic features with the result that the phonetic processor is presented with auditory information favoring the strong-ear signal. In this model, the relative magnitude of the weak-ear deficit is seen to be a function of: (1) the susceptibility of the weak-ear signal's auditory features to transmission loss, and (2) the similarity and strength of

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[6]Support for a general model of this sort has been provided by the results of several experiments, e.g., Studdert-Kennedy and Shankweiler (1970); Milner, Taylor, and Sperry (1968).

the weak-ear signal's auditory features relative to those of the strong-ear signal[7].

Is the Interaction of Weak and Strong Ears a Form of Dichotic Masking?

It might be suggested that the auditory interaction between strong- and weak-ear signals discussed above is a form of dichotic auditory masking. Many studies (e.g., Deatherage and Evans, 1969) have shown, for example, that the processing of a target presented to one ear is compromised by the presentation of an acoustically similar mask to the opposite ear. It should be noted, however, that such interaction between dichotically presented signals occurs only when the mask is of greater intensity than the target. When the mask and the target are of equal intensities very little masking is found. This relationship between masking effects and intensity of the mask is not the same as that seen in the present study. The weak-ear "target" is suppressed by a strong-ear "mask" even when the mask is 20 or 30dB less intense than the target. This discrepancy suggests that the interaction between dichotic signals may have a different character depending upon the type of signals employed and, possibly, the type of task required of the subjects[8].

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[7]Studdert-Kennedy, Shankweiler, and Pisoni (1972) have recently reported data consistent with the model proposed here. Their Ss were asked to identify both stimuli in a dichotic CV identification task. As expected, Ss did more poorly identifying the left-ear CV than in identifying the right-ear CV; the relative size of the left-ear deficit tended to be largest, however, when the signals of both ears were acoustically (but not phonetically) similar. Phonetic (but not acoustic) similarity, on the other hand, increased overall performance but not the relative size of the left-ear deficit. Their results are consistent with our model and they concluded, as we have, that such results "...justify the distinction (made) between auditory and phonetic processes." However, even though they suggest auditory stage interference as a basis for explaining part of their results, their interpretation differs from ours in that they apparently view the phonetic stage to be the "primary level of dichotic competition." Further experimentation will be required in order to resolve this apparent difference in interpretation. It may be, of course, that interaction occurs at both levels of processing.

[8]Masking studies usually employ a signal detection paradigm, whereas the present study employs a signal identification task.

There is additional support for the suggestion that the traditional dichotic masking effects reflect a different sort of interaction of signals than that suggested by the results of the present study. This support is provided by the results of experiments indicating that introduction of a temporal asynchrony between target and mask has different effects depending on whether the dichotic signals are speech or non-speech. In traditional masking studies utilizing non-speech sounds the introduction of increasing target/mask asynchrony results in monotonically decreasing masking. When a similar asynchrony is introduced between the ears in a dichotic CV identification task, however, suppressive effects are a non-monotonic function of increasing asynchrony (Kirstein, 1971; Porter, 1972; Studdert-Kennedy, Shankweiler, and Schulman, 1970; Berlin et al., 1972a).

It would seem that the interaction of dichotically presented speech signals involves a different sort of process than that underlying the interaction of signals in traditional dichotic masking studies. We would like to suggest that this difference may reflect the specialization of the human auditory system for the detection and analysis of the special acoustic features of speech.

Interpretation of Normals' Data in the Context of the Model

The data for normals in the present experiment can be interpreted in the following ways:

1. A strong-ear vowel tended not to suppress weak-ear CV performance since a vowel has only a few acoustic properties similar to those of the CV's. (The same interpretation could be made of the small suppression which has been previously observed for strong-ear noise [Berlin, Lowe-Bell, Cullen, Thompson, and Stafford, 1972b].) A strong-ear bleat, on the other hand, substantially suppressed left-ear performance because it has several acoustic features in common with CV's.

2. There was a systematic change in the left-ear deficit with variations in the intensity of the strong-ear signal. Since intensity, in context of the present study, is an acoustic and not a phonetic feature, these variations in suppression are consistent with a model in which the interaction of signals is said to occur in terms of the relative strengths of two signals' auditory features.

3. The bleats tend to suppress weak-ear performance less than CV's at the high intensity values and more than CV's at the low intensity values. This tendency may be explained in terms of the different spectral distribution of acoustic energy for the bleats and CV's. At a given intensity,

the bleats have their acoustic energy concentrated in the second and third formant regions. For CV's at the same intensity, on the other hand, the same total energy is distributed between three formants with a large proportion being concentrated in the first formant. If the weak- and strong-ear signals may be assumed to be interacting in terms of the relative strengths or energies of their respective acoustic features, then at lower intensities a strong-ear bleat might provide relatively more interference with weak-ear CV's second and third formants than would the same intensity CV. Bleat suppressive effects might, therefore, be greater than CV effects at these intensities even though the bleats share fewer acoustic features with the weak-ear signal than does the CV.

Extending the Model to Patients' Data

It seems to us from these data and from data reported elsewhere (Berlin, Lowe-Bell, Jannetta, and Kline, 1972c; Shankweiler, 1966) that some acoustic feature processing capability has been lost following temporal lobe lesions. Further, we conclude along with others that both the left- and right-temporal lobes must participate in the auditory stage of speech signal processing, otherwise there would be little change in dichotic performance after temporal lobe lesions. This information taken within the framework of the auditory interaction model developed above provides a basis for interpreting the patients' data. Comparison of patients' and normals' data reveals a similar pattern of suppressive effects, the principle differences being in the magnitude of overall effects and in the relatively greater suppressive effects seen for vowels in the patient data. The generally greater suppressive effects seen for patients can be attributed at least in part to the disturbance of the auditory analysis of the weak-ear signal resulting from the loss of contralateral auditory association cortex. This disturbance of the processing of the weak-ear signal's acoustic features may, in addition, be severe enough to allow even the relatively acoustically dissimilar vowel to cause the substantial suppressive effects observed.

We therefore suggest that the demonstration of a weak-ear deficit usually depends on three factors:

1. The dichotic presentation of stimuli with similar speech-like acoustic properties*.

2. The relatively poorer auditory representations of the acoustic features of the weak-ear's signal.

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*Dichotic competition is not <u>always</u> necessary, however.

3. The requirement that the processing of the weak-ear signal involve special phonetic decoding at a single processor located in the left hemisphere.

Under these three conditions the auditory representations of the acoustic features of both ears' signals are assumed to interact. The weak-ear signal is most labile because it must traverse a longer and less efficient pathway in the case of the normals or, as in the case of patients, is transmitted through lesioned auditory cortex. The special phonetic processor is consequently presented with auditory information favoring the acoustic features of the strong-ear signal. As a result, perception of the weak-ear signal is compromised and suppression of weak-ear performance is seen.

Our current research is examining further the suggested specialization of the auditory system for the detection and analysis of the acoustic features of speech.

CONCLUSIONS

In summary we have shown that:

1. The normal listener has a right ear dichotic speech advantage.

2. He also shows a "lag effect" -- the trailing message in a pair is more intelligible in the 30-60 msec range.

3. Patients with temporal lobe lesions show no lag effect and a marked weak ear deficit.

4. Patients with temporal lobectomies and hemispherectomies seem to have lost the neural homologue of acoustic information rather than phonetic information as a result of their brain lesions.

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Paper 1 - Berlin, C. I., Lowe-Bell, Sena S., Jannetta, P. J., and Kline, D. G., Central auditory deficits after temporal lobectomy. Arch. Otolaryngol., 96, 1972, 4-10.

Paper 2 - Berlin, C. I., Lowe-Bell, Sena S., Cullen, J. K., Jr., Thompson, C. L., and Stafford, Marion R., Is speech "special"? Perhaps the temporal lobectomy patient can tell us. Letter to the Editor, J.A.S.A., 52, 1972, 702-705.

Paper 3 - Berlin, C. I., Lowe-Bell, Sena S., Porter, R. J., Jr., Berlin, Harriet L., and Thompson, C. L., Dichotic signs of the recognition of speech elements in normals, temporal lobectomees, and hemispherectomees. IEEE Group on Audio and Electroacoustics Transactions, 1973, (In Press).

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