VERBAL AND NON-VERBAL CEREBRAL PROCESSING IN MAN FOR AUDITION

Thesis by

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ABSTRACT

Hemispheric asymmetries were investigated with various auditory techniques in several groups of subjects. The first study was a dichotic listening experiment in which two separate musical chords were presented simultaneously one to each ear of right-handed males. The subjects were required to listen to the chord stimuli and then recognize them from a multiple choice of four chords heard immediately following the dichotic presentation. More chords were recognized from the left ear than from the right implying right cerebral dominance for this task. In a similar test, dichotic presentation of melodies showed no difference between the ears. It was hypothesized that the subjects in this case were identifying the tune segments on the basis of rhythmic rather than pitch cues. It was suggested that the right hemisphere is superior to the left in processing stimuli that are "non-temporal."

Musical expression was investigated in patients who had transiently lost the function of one hemisphere following intracarotid amytal injection. It was observed that after right hemisphere depression, singing was devoid of pitch at a time when speech was only minimally disturbed. Conversely, singing was much less affected than speech after left hemisphere depression. This differential effect of amytal depression is supportive of the idea that the right hemisphere is used for pitch control in singing whereas the left hemisphere is used expressly for speech.

Singing was also studied in two young patients with surgical hemispherectomies for non-infantile causes. One patient who had a right hemisphere removal with no evidence of aphasia, sang most songs poorly. He also failed pitch discrimination tests wherein he could not distinguish two tones that were separated by an interval of less than one musical step. Another patient with a left hemispherectomy produced the opposite results. She had great difficulties in expressive speech yet could sing with excellent pitch control and intonation. These cases

support the previous conclusion that the right hemisphere is necessary for correct pitch production in singing.

Dichotic listening studies on patients with complete surgical division of the corpus callosum indicated that the right hemisphere also had some capacity to understand and manually express verbs and verbal commands. This was evidenced in instances where only the command presented to the left ear was manually performed at a time when another command presented simultaneously to the right ear was the only one that was verbally reported. The indication is that the right hemisphere understood and performed the required action when the left hemisphere was apparently unaware. However, it was also shown that for most dichotic verbal tests the left hemisphere still has dominant control over the right.

Dichotic listening studies also indicated that the left hemisphere could separately monitor stimuli in the ipsilateral along with stimuli in the contralateral pathway. This was contradictory to previous conclusions that the contralateral pathway suppresses the ipsilateral in dichotic competition. Response time studies carried out in these callosum-sectioned patients investigated organization of the two cortical systems that separately analyzed stimuli from the two ascending paths.

It was found that response times for repeating words to the right ear were faster than for words in the left ear. Control tests showed the cause of this difference was not in delay of transmission in ascending routes, nor in differences of perception in the two systems. It was deduced that the cause was an asymmetrical process of memory retrieval for translation into motor impulses to the speech apparatus.

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INTRODUCTION

Auditory functions have asymmetrical representation in the cerebral hemispheres as have cognitive abilities in the visual(1,2,3,4,5) and tactual modalities(6,7,8,9). Right-left differences are commonly investigated by comparisons of patient groups with severe unilateral lesions. For example, a standard auditory test is given to patients with right hemisphere damage and their scores are compared to those obtained by patients with left cerebral damage. Differences in scores imply differences in cerebral function. The first experiments designed to measure right-left differences for non-language auditory tasks were undertaken just over a decade ago where standard musical abilities tests were administered to temporal lobectomy patients(10). These findings were the first systematic results indicating that the right hemisphere was superior to the left for certain auditory functions. These were surprising at the time since they refuted standard beliefs that music had functional representation along with speech in the left hemisphere(11,12,13).

It is worthwhile to seek out other patient groups who are perhaps better suited to be investigated for asymmetries of musical and other cognitive abilities in the cerebral hemispheres. An example of one such group of patients are those few who have had surgical removal of the cortex of one entire hemisphere. In these cases one can directly ask the one remaining brain half (whether it be the left or the right) what type of functions it has retained and which it has lost. One can ask it to speak, think, sing, laugh, cry and do all the things two brain halves normally do. The burden is on the examiner to ask the right questions.

Whereas cases of hemispherectomy are not frequent, there is a number of other patients in whom it is necessary to artificially induce symptoms of hemispherectomy, as a pre-surgical procedure. This is accomplished by intracarotid injection of sodium amobarbital which has the effect of producing unilateral cerebral depression while, at the same time, permitting concomitant functioning of the non-injected hemisphere. The depression lasts for a few minutes during which time certain cognitive tests can be employed to assess the particular abilities of the non-depressed hemisphere.

Asymmetries of cerebral function may also be measured in normals when special techniques are employed that are capable of separating out the cognitive ability of each hemisphere. Dichotic listening is one of these techniques, making use of the fact that competing aural inputs to the two ears tend to induce right-left perceptual differences that reflect asymmetries in cerebral performance. Interpretations of these experiments are based on assumptions that the contralateral ear-to-cortex pathway is dominant. Therefore, when verbal tasks show asymmetry in favor of the right ear, it is concluded that the left hemisphere is superior for those tasks(14,15). Conversely, when verbal stimuli are used, ear dominance is found to switch to the left ear indicating a right hemisphere superiority(16). This technique has become an important tool for determining left-right cortical specialities of particular verbal and non-verbal stimuli.

The transient state of hemispheric depression in patients with intracarotid amytal and the presence of transcallosal communication in normal subjects often limits the types of investigations that may be performed. The availability of a small population of human subjects in whom the cross-communicating fibers have been surgically divided for control of intractible epilepsy provides an opportunity to avoid these problems. Dichotic listening studies, which had previously depended on a statistical analysis to establish ear asymmetries, now demonstrate a striking difference between the ears in which there is a complete extinction of the non-dominant ear(17,18). Consequently, one can assume under normal dichotic listening conditions that an essentially direct auditory channel from the left ear to the right hemisphere and from the right ear to the left hemisphere could be attained. In addition, these patients provide an opportunity to study ipsilateral and contralateral auditory pathways when the responses to ear stimuli are analyzed from only one hemisphere.

The present series of works use the above-described auditory techniques as tools to investigate the expressive and receptive auditory abilities that are specialized in one or the other cerebral hemisphere of man.

I. HEMISPHERIC ASYMMETRIES IN THE PERCEPTION OF MUSICAL CHORDS

Introduction

Interest in cerebral organization of auditory stimuli has led to human studies on the perception and production of music and other non-spoken sounds. Left-right hemispheric asymmetries for verbal and non-verbal stimuli have been found in audition just as in the visual and tactual modalities. In general, the left hemisphere has been concerned with verbal mediation while the right with more spatially-oriented forms of perception. For example, visually presented non-sense figure recognition and spatial relation tasks are performed better by right-handed patients with unilateral left compared with unilateral right cerebral lesions (1,2,3,4,5). Similarly, the intact right hemisphere excels in certain tactual form and pattern recognition tasks (6,7,8,9,10). In addition, demonstration of dyscopia for forms with the right hand and dysgraphia with the left in cerebrum-sectioned humans amplifies the left-right dichotomy of the cerebral hemispheres for verbal and non-verbal functions (11). However, the left hemisphere in addition to its major role in speech (12) may also dominate in perceptual situations where verbal analysis can play a part in the stimulus processing (13, 14).

Although participation of both hemispheres cannot be ruled out in dealing with any non-verbal task including audition, the non-dominant hemisphere is presently implicated as the more instrumental for musical functions. Early conclusions of cerebral lateralization for music had been drawn exclusively from clinical case reports.

Some patients who suffered illnesses which resulted in severe aphasia, one to the extent of complete speechlessness, could nevertheless sing familiar songs or reproduce known melodies (15,16,17). Other patients, however, whose musicianship was known before illness selectively lost their musical talents with little or no aphasic disturbances (18,19,20). It must be pointed out that not all agree on lateralization of musical functions to the right hemisphere. A possible source for confusion, however, is the several different aspects of music that are discussed by different authors as can be seen in a brief review of amusia by Bogen(21). Systematic investigation for right hemisphere superiority for some musical functions was tested by Milner(22). She found patients with left temporal lobectomies to have significantly greater scores than those with right temporal lobectomies on some subtests of the Seashore Test of Musical Abilities (23), notably the Timbre and Tonal Memory. Her work was among the first to provide a start toward the systematic determination of particular non-verbal auditory information that is better handled by the non-dominant hemisphere.

Further studies issuing additional insights for musical functions were made by Kimura using the technique of dichotic listening (24). Brief portions of Baroque melodies were played to normal volunteers so as to set one ear against the other in a melody recognition task. It was found that more selections were correctly chosen from those that had been played to the left ear. The conclusion supports a superiority of the right hemisphere for melody recognition since binaural stimulus rivalry causes the contralateral auditory pathways on route to the higher brain centers to dominate, thereby suppressing information in the ipsilateral ear-to-cortex projection(25,26). The hemispheric asymmetry has been substantiated with orchestrated melodies in patients with unilateral temporal lobectomies by Shankweiler(27). In his study, patients with their right temporal lobes removed were significantly inferior in dichotic melody recognition to those with left lobectomies. However, for verbal material (digits) also presented dichotically, the absence of the left temporal lobe produced the greatest deficit.

The present study focuses on the more elemental aspects of orchestral melodies that might have caused the lateralization effect in previous dichotic listening work. Accordingly, two tests of musical functions were devised so that melody and rhythm were separated from timbre and chordal qualities. The first test consisted of melodies played on a recorder--an instrument with a whistle-like tone largely devoid of timbre and chordal variation. These latter aspects were diverted to the second test where the dichotic stimuli consisted entirely of chords prepared from an electric organ rich in overtones for timbre quality. It was hypothesized that dividing the notable characteristics of orchestral melodies into separate tests, a more precise statement of musical lateralization could be made.

Material and Methods

Subjects

The subjects were 20 male college students with an average age of 19 years and I.Q. estimated to be above 120. They were members of performing musical organizations but were told initially that they must be right-handed and have no known hearing defects in spite of their musical abilities. Beyond these clues they had no previous knowledge of the purpose of the study.

Testing Procedures

The testing session consisted of three auditory tests and the Harris Tests of Lateral Dominance (28), all of which were administered to the subjects on an individual basis. Each subject received the auditory tests in a single one hour session that included several brief rest periods. They knew they were to receive a monetary compensation based on their test performance. The tests for lateral dominance were administered after the auditory test session in most cases.

Digits Test

Using the techniques of Broadbent(29) with Kimura's modifications (30), two sets of digits were presented dichotically--one set to each ear through stereo headphones. Each set contained three of the numbers, 1 through 9, played in succession but separated by 0.5 second intervals (Fig. I-la). The two sets competed such that the first digit heard by one ear occurred simultaneously with the first digit heard by the other ear, and so on for each of the digits. A total of 6 digits (or 3 simultaneous pairs) were presented in any one trial. After each trial sufficient time was allowed for the subject to write down, in any order, as many of the digits as he could remember. There were a total of 30 trials and the same digit did not appear more than once during a single trial. Half of the subjects started with the left stereo headphone on the left ear and the right headphone on the right ear; the other half started in the opposite positions. After the 15th trial the headphones were reversed in all subjects.

Melodies Test

Eighty melodies were chosen from Baroque literature or obscure dances and were taped with a Sony Model 350 stereo tape deck using a soprano or alto recorder. The melodies were four-bar motifs with the tempos arranged so that each melody would be 4 seconds in duration. After a warning signal of two binaural tones, two of the melodies matched for rhythm and pitch range, were then played binaurally in succession after the dichotic melodies, but were separated by 3-second intervals (Fig. I-1b). The subject was to select the original two melodies from the four choices and indicate them by checking two corresponding boxes on an answer sheet. There was a total of 20 trials preceded by 2 practice trials. The starting positions of the headphones were the same for the subjects as in the Digits Test. The headphones were reversed after the 10th trial.

Chords Test

This test was administered exactly like the Melodies Test but with four exceptions. These were: 1) chords instead of melodies,

2) no warning signals, 3) four (rather than 2) practice trials, and 4) 2-second (rather than 4-second) stimulus durations. Also, there was a total of 40 trials divided into 4 sets of 10. Each chord was recorded from an electric organ and consisted of four tones: the tonic, 3rd, 5th, and either the octave or the 7th. The tones were not played as an arpeggio but all four sounded at once. The tonics for the four chords in any one trial were chosen so that any two had the smallest possible interval, but also that the two dichotic chords followed these criteria. Set I: Only major chords were used but none of the four tones in one chord matched any of the four tones in the other; Set II: None of the four tones of either chord matched, but both major and minor chords were used; Set III: Two of the tones of the dichotic chords were the same; Set IV: The dichotic chords were made up of two of the following four forms of the same chord: 1) major, 2) minor, 3) major 7th or 4) minor 7th. The pattern of recognition and selection followed the form of the Melodies Test where the two correct chords were selected from four choices and indicated on an answer sheet(Fig. I-1c). The subjects started with the headphones as they had in the previous two tests, reversing them after Set II.

The three auditory tests were given in two sequences: Digits-Melodies-Chords or Melodies-Digits-Chords, with half of the subjects taking the sequence in the first order and half in the second. The tests were scored at the end of the auditory test session and payments were made at that time.

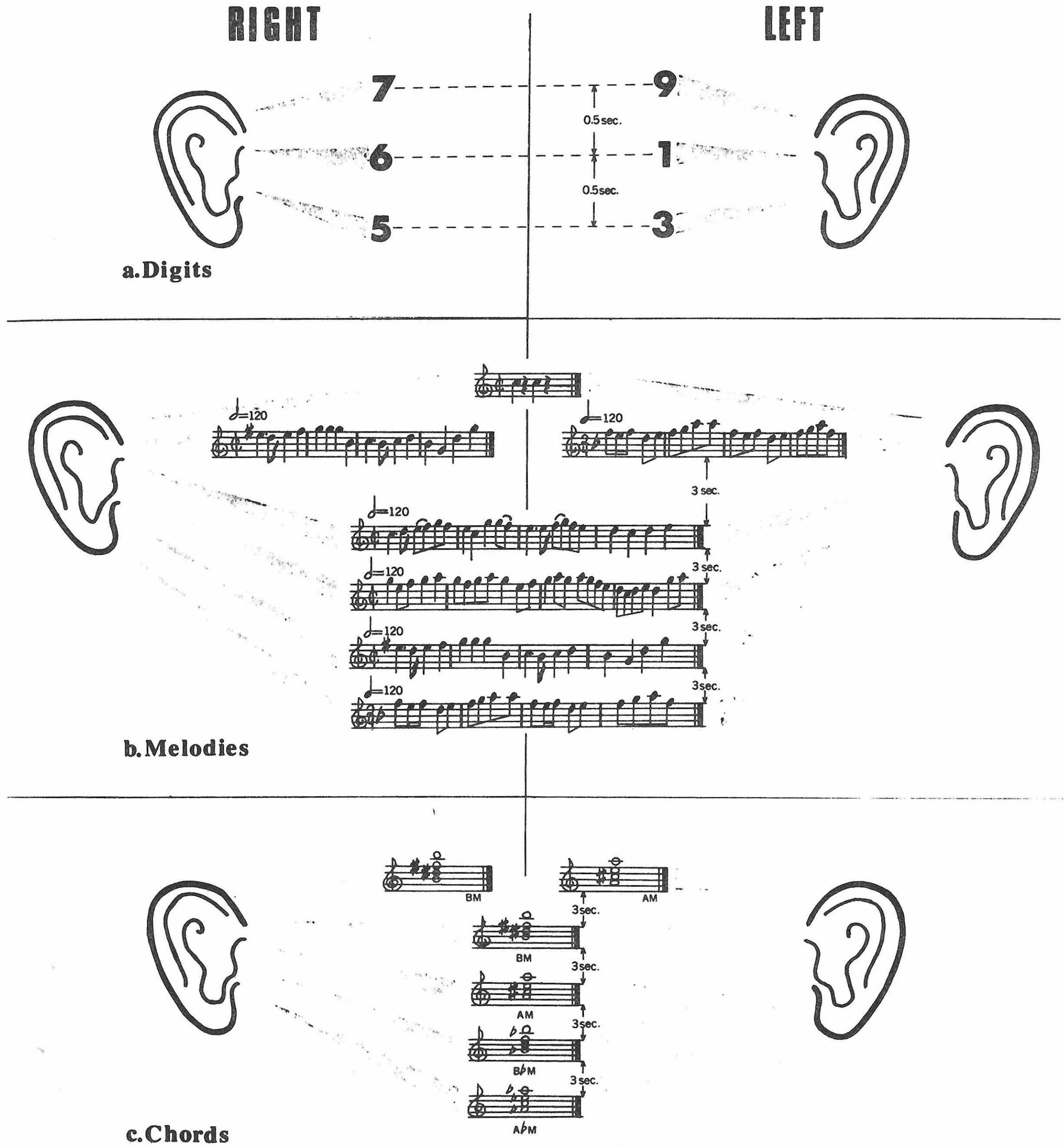

Figure I-1: Diagrammatic description of auditory tests. a. Digits: Three simultaneous pairs of numbers; b. Melodies: First, warning tones; then, a pair of melodies played simultaneously; finally, four binaural melodies; c. Chords; First, a pair of chords played simultaneously; then four binaural chords.

Results

Each of the subjects was found to be right-handed, footed, and eyed by the Harris Test of Lateral Dominance. The scores of the group who took the Digits Test before the Melodies Test were indistinguishable statistically from those of the group who took the tests in the reverse order ($p > 0.10$). Thus all subjects are considered together in the comparisons that follow.

TABLE I-1

Left-Right Mean Differences for the Auditory Tests

Test	Means (% correct) (Prob. of obtaining this score or more) Left Ear	Right Ear	t* (df = 19)	P
Digits	85.0 (94.5%) ($p < 0.001$)	86.35 (96%) ($p < 0.001$)	-1.59	NS**
Melodies	15.5 (77.5%) ($p < 0.01$)	14.7 (73.5%) ($p < 0.03$)	1.01	NS**
Chords	28.35 (71%) ($p < 0.01$)	25.05 (63%) ($p < 0.05$)	2.738	< 0.02

*A negative t indicates a larger mean score for the right ear.

**NS = not significant ($p > 0.10$)

The mean scores for the left and right ears were compared for each auditory test with the Student's t Test for correlated means. The results are presented in Table I. It is clearly seen that the Digits Test shows a higher mean score for the right ear, but fails to be statistically significant. Although the left ear was slightly favored, the mean scores for the two ears in the Melodies Test were nearly the same, highlighting a statistical lack of superiority for either ear. The Chords Test, on the other hand, reveals a significant left-right difference between the mean ear scores. Comparisons of the two means by Student's t Test allows us to conclude with less than 2% uncertainty that the left ear is better than the right. Actually the scores for the right ear for this test do not significantly differ from a chance level ($p > 0.05$), while the left ear scores do ($p < 0.01$). Indeed, not only do the left-right scores differ significantly from each other but only one ear, the left, is able to perform the task at all.

The superiority of the left ear in the Chords Test is even more striking when considering the number of subjects who demonstrated the effect. Seventeen out of 20 subjects had higher scores for chords presented to their left ear while only three preferred chords in their right ear. This distribution of subjects could occur by chance less than ½ of 1% of the time. In contrast for the Melodies Test, 10 subjects showed a right ear preference, 9 preferred the left ear and one showed no difference. This result is exactly what one would expect from a chance distribution. For the Digits Test, the distribution was 13 subjects with a right ear preference, 5 with a left ear preference, and 2 subjects showed no difference. This distribution was only significant at the 10% level. These comparisons are summarized in Table I-2.

TABLE I-2

Ear Preferences for the Auditory Tests

Test	Subjects better in: Left Ear	Right Ear	Neither Ear	P
Digits	5	13	2	<0.10
Melodies	10	9	1	NS
Chords	17	3	0	<0.005

It was observed that the subjects generally improved their scores during the second half of each test. Although this was attributed in part to differential test difficulties, practice effect was also suspected. An interesting aspect of the score changes, however, would be an asymmetrical increase (or decrease) in performance of one ear versus the other. Using the Student's t Test, the means for the first and second parts of each test were compared for each ear separately. The results are presented in Table I-3. The left ear shows significant improvement in the Chords Test only, and little change in the other tests. Only non-significant improvement trends are evident for the right ear. It appears that on the one test where a statistically significant left-right difference occurred, a significant improvement was also shown for the superior ear.

TABLE I-3

Mean Score Comparisons of Part 2 to Part 1 for Each Ear

Test	Left Ear	Right Ear
Digits Part 1 vs. Part 2	*t = 1.48 ($p > 0.10$)	t = -1.82 ($0.08 > p > 0.07$)
Melodies Part 1 vs. Part 2	t = -1.53 ($p > 0.10$)	t = -2.03 ($0.06 > p > 0.05$)
Chords Sets I+II vs. Sets III+IV	t = -2.48 ($0.04 > p > 0.03$)	t = -1.98 ($0.07 > p > 0.06$)

*A positive t indicates Part 1 to have a higher mean score than Part 2.

Discussion

Only the Chords Test resulted in any significant left-right differences in ear performance. As had been shown for melodies in earlier work, the left ear exceeded the right in recognizing chords that had been played dichotically. Surprisingly, however, the present Melodies Test failed to follow this pattern. Neither ear exhibited a superior performance which is a result that not only conflicts with the Chords Test but also with previous conclusions that the left ear, and thus the right hemisphere, is superior for melody recognition. It is apparent that caution must now govern assignment of musical functions to the right hemisphere.

These tests were constructed with the idea that each would provide unique musical characteristics to serve as cues for subjects to select the dichotic stimuli from a group of multiple choice possibilities. The characteristics were chosen to be common subdivisions of musical function. To the extent that these are natural with respect to distinct musical brain functions is an open question. The following analysis will help shed light on asymmetrical hemispheric function for musical and other non-verbal auditory stimuli.

The Melodies Test contained two musical qualities: Rhythm patterns and pitch variations. Either or both of these could have been used as cues to distinguish the individual melodies. Timbre was virtually excluded by the whistle-like sound of the recorder; and other musical features, such as loudness were controlled.

On the other hand, the Chords Test excluded all temporal aspects of music. The unique qualities of the chords were simply the pitch differences of one chord compared to another, or perhaps more properly, the <u>pattern</u> of pitches peculiar to a given chord contrasted with the pitch pattern of another. Also present were rich tonal qualities and timbre although it was hard to determine whether these provided unique cues for each chord.

These test analyses propose two distinct cues for the Melodies: rhythm, and pitch--temporal, and non-temporal qualities, respectively; and essentially one cue, pitch or pitch patterns, for distinguishing the Chords. If we assume for the moment that pitch is the determining factor in the Melodies Test, then it must be qualitatively different from the pitch discrimination in the Chords Test to explain the conflicting results of the two tests. The most likely source of this difference is the contrast between the simple tone-to-tone pitch variations of the melodic line and the "pattern" of pitches produced by the chords. If this be the case, it follows that hemispheric asymmetry could be demonstrated for the latter but not the former type of pitch discrimination. This argument is weakened considerably by the superior ability of the subjects with intact right hemispheres making tone-to-tone comparisons in Milner's lobectomy studies with the Tonal Memory Subtest of the Seashore Tests of Musical Ability. Milner's evidence strongly suggests that the present subjects should have demonstrated a cerebral asymmetry if they had used pitch variations to discriminate the melodies.

Since there was no asymmetry, it seems likely that non-superiority of either ear in the Melodies Test is due primarily to the rhythmic aspect rather than any qualitative pitch differences. That is, the subjects were able to select the correct melodies by noting the rhythmic patterns unique to each of the dichotic pair rather than the variations in pitch. The equal performance of the two ears suggests the bilaterality of rhythmic function.

Bilaterality of rhythm is supported by the temporal lobectomized patients' performance on the Seashore Test(22). Contrary to superiority of the left lobectomized patients (right hemispheres intact) in the Tonal Memory Subtest, the Rhythm Subtest showed no difference between the left and right lobectomized groups. More recent work by C. Darwin(31) further substantiates cerebral asymmetry for perception of tonal differences. He obtains a left ear superiority for discrimination of the successive tones that formed "shapes" such as ascending or descending lines, or "Vees".

In still another study, patients were injected with sodium amobarbital such that their right hemispheres were momentarily depressed for clinical tests(32, and Section II). Under this condition, attempts at singing revealed gross melodic disturbances with little loss in rhythmic sense. This emphasized the important presence of rhythmic function in the left hemisphere.

It was suggested (33) that lateralization of rhythm to the left hemisphere might also account for the results on the Melodies Test. That is, a predominance of rhythmic function in the left hemisphere could produce the observed results and confound the conclusions. The subjects would recognize unique rhythms in some trials and unique melodic changes in others so that the overall performance would show no asymmetry. This scheme would have to be followed randomly since no specific trials consistently favored one ear. That is, selection of the rhythm aspect or pitch was a random choice of the subject and not a function of particular trial melodies. Further investigation of this question is needed--perhaps using variable rhythm with constant pitch variation, and variable pitches with constant rhythms. At this point, however, the bilateral rhythm hypothesis seems the most attractive.

We conclude that the present subjects chose to use the rhythmic cues in the melodies and not the pitch changes to perform the discrimination task. The reason for this is not clear. Subjectively, it might be expected that the use of the recorder rather than tone-rich orchestral instruments produced sounds in which rhythms were more striking and the pitch changes more subtle. A comment by one of the subjects supports this notion. The subject was one of the few who complained that the dichotic melodies were very difficult compared to the chords. His remark is significant in that he is a percussionist who is particularly attentive to rhythms and automatically used these as the important cues. The proposed bilaterality of rhythm caused both hemispheres to be in conflict, making the task particularly difficult and confusing for this subject. Other subjects probably experienced this conflict but were normally less concerned with rhythm and therefore less disturbed.

When in a single trial, the rivalry between the melodies resulted in only a single correct response, the chosen melody could equally well have come from either the left or right ear. In contrast, rivalry in the dichotic chords resulted in correct answers most often from the left ear implicating right hemispheric superiority.

Although ease of the Digits Test for these subjects resulted in scores that were too high to show a statistically significant deficit for the left ear, the strong right ear trend supports previous reports of right ear superiority for verbal material. On the other hand, the scores for the Melodies Test were not remarkably high, so the non-significance of the mean differences, in spite of a small left ear bias, must be attributed to factors other than bilaterally good performance. Attention primarily to rhythmic cues with either ear serves as the hypothesis in this Section to illustrate the point. The Chords

Test was the most difficult for the subjects and yet distinguished most clearly a superior left ear. Indeed, comparison of performances between the first and last halves of the test indicated the left ear improved more readily than the right. This may reflect a greater ability for the right hemisphere to learn, in addition to perceive and recognize, chordal stimuli. The dichotic listening technique cannot be expected to separate the functioning of the cerebral hemispheres in normal subjects as completely as in patients in whom the neo-commissures have been surgically divided(34), but demanding tests such as the present Chords Test results in statistical differences in ear performance of auditory tasks from which implications of functional lateralization and organization of the cerebral hemispheres are drawn.

II. CEREBRAL LATERALIZATION OF SINGING AFTER INTRACAROTID SODIUM AMOBARBITAL (in collaboration with Dr. J.E. Bogen)

Introduction

Musical expression in patients with cortical lesions has been discussed in a number of clinical reports. The accounts are largely anecdotal since they are presented primarily as a contrast to concomitant disturbances of language and speech. One of the earliest examples, published in 1745(1), is a description of a 33-year-old man who, after a sudden right hemiplegia, found himself unable to utter any word except, "yes". Nevertheless, it was stated that he could

> "...sing certain hymns which he had learned before he became ill, as clearly and distinctly as any healthy person."

This account typifies many such cases subsequently published where left hemisphere damage produced deficits in speech, not accompanied by disturbances of singing, instrument playing, or other musical abilities(2,3)

Lesions in the right hemisphere have conversely produced major deficits in music skills while speech was largely unaffected(4,5,6,7). One recent case(4) was a musically talented man who was operated for a tumor in the right hemisphere. Subsequent to surgery he not only failed consistently to sing songs that he had previously known quite well, but also lost his ability to correctly imitate single intervals or short tunes. In contrast, speech disturbances were mild and temporary.

Not all cases of aphasia without amusia, or of amusia without aphasia were sufficiently clear-cut to characterize music ability as a functional capacity of either the left or right hemisphere alone(3,8).

Speech disturbances were noted along with musical dysfunction in some patients; lesions were often diffuse or poorly defined. Also, the question of functional compensation or cerebral reorganization in non-damaged cortex was an undeterminable factor.

The lateralization of musical functions was first studied systematically by Milner(9). She found deficits in tonal memory and timbre in patients who had had right but not left temporal lobectomies. Other studies including dichotic listening on normals(10,11)as well as on brain-damaged patients(12,13) have also demonstrated right hemisphere lateralization of musical perception.

Systematic studies of musical <u>expression</u> rarely have been reported. A renowned composer continued to produce musical masterpieces after a vascular accident in the left hemisphere which had rendered him severly aphasic(14). Singing was observed in another case of a 46-year-old man whose left (dominant for speech) hemisphere was surgically removed because of a recurrent tumor(15,16,17). In this patient, good melodic quality and articulation were described in spite of greatly impaired speech. Two other hemispherectomy cases are supportive of these observations. (See Section III-A) The first is a young adolescent female whose excised dominant hemisphere produced moderately impaired speech which at the same time did not apparently affect her singing ability. The second patient is a young adolescent male who had a non-dominant hemispherectomy. He spoke very well but could not carry a tune except in simple songs with which he was most familiar (e.g. "Happy Birthday"). The notion that the right hemisphere is dominant for certain musical functions is supported by the observations on these patients but not conclusive since pre-operative investigations were not carried out.

Some of the uncertainties surrounding the data from surgical hemispherectomies, or lateralized ablation in general, can be eliminated by a systematic study of patients with transient, reversible inactivation of one cerebral hemisphere. This condition is induced by intracarotid injections of sodium amobarbital(amytal) in order to determine hemispheric lateralization of speech where left-right contributions are in doubt(18). The amytal acts almost instantaneously to depress most, if not all, hemispheric functions on one side for a period of 3-5 minutes, during which time the non-injected hemisphere operates on its own--seeing, hearing, feeling, and controlling the muscles on the contralateral side of the body--not unlike the usual behavior after a surgical hemispherectomy. Speech lateralization can be confirmed if, after injection into one artery, the patient continues to speak, whereas injection into the other artery produces speech arrest.

Once speech lateralization is established, there is usually some time remaining before recovery during which one can examine other functions including singing(19). If the observations from the surgical hemispherectomy cases are indicative, one would expect to observe major disturbances in singing and mild disturbances in speech after right hemisphere depression and the reverse after left depression. Our results followed this model but with some unexpected qualifications.

Subjects and Procedure

The subjects were eight epileptic patients who were candidates for major brain surgery and in whom it was necessary to determine the contribution of the cerebral hemispheres to speech. All patients had right carotid artery injections which maximally depressed the right hemisphere but not the left. Five were also injected in the left carotid artery. at least two days after the right-sided injection.*

The examination period commenced with injection of sodium amobarbital and terminated minutes later with patient's recovery from hemiplegia. Hemispheric dysfunction was indicated by contralateral flaccidity and lack of response to verbal command in the paralyzed limbs. Unilateral depression was also accompanied by eye deviation to the injected side and by general drowsiness.

Throughout the session speech samples were recorded in which the patients repeated words and phrases or answered questions. Comprehension was also tested by requesting performance of simple motor acts (e.g. clenching and unclenching the fist, extending a finger, etc.) with the non-paralyzed limbs. The same protocol was not followed in each case since testing material depended on the specific responses of the patient.

Singing was induced by verbal request of the title of songs familiar to the patient. Usually, the examiner would also start to sing the first few bars to facilitate the response. The patient was encouraged to sing the song without worry about his vocal performance and with assurance that his best try would be sufficient.

*All injections were performed by Dr. J.E. Bogen and staffs of the White Memorial Medical Center, Los Angeles, and Rancho Los Amigos Hospital.

A pre-examination session commenced just prior to introduction of sodium amobarbital but subsequent to insertion of the needle into the carotid artery. During this period, the patient became acquainted with the test material. He was asked to state his name, the date, and to repeat several words and sentences. These were recorded on audio tape and used as baseline speech samples to which the future test material, to be presented during hemispheric depression, could be compared. The patient then sang songs with which he was familiar; these were also recorded for later comparison. The pre-examination terminated when the patient was comfortable with the test situation and acquainted with the test material.

In preparation for amytal injection the patient was positioned on his back with his knees drawn up and arms raised straight above his chest. He started to count aloud slowly (1,2,3,...) and, at the same time, to clench and unclench his fists. The sodium amobarbital (usually 200 mg in 10% solution) was injected in a period of 1-2 seconds; almost immediately the contralateral arm and leg relaxed to a flaccid state while the ipsilateral limbs remained strong and active.

The behavioral testing procedure described for the pre-examination session was now repeated during the depressed state of one hemisphere. The patient was asked to state his name, the date, and to repeat a few words and phrases. Commands such as "Make a fist," "Wiggle your toes," or "Stick out your thumb," were requested verbally or by demonstration and were designed to test comprehension and motor control through use of limb movements. Finally, the examiner stated the title or sang a few bars of the songs that were practiced during the pre-injection period until the patient started singing. The patient was usually encouraged to complete the song using only "La, la, la,..." instead of words, concentrating mainly on the melody.

Repeated checking of the responsiveness of the flaccid limbs provided an indication of the level of hemispheric dysfunction. As long as unilateral depression was observed, the motor, speech, and singing responses were primarily controlled by the non-injected hemisphere. Once the previously paralyzed limbs could move, either spontaneously or to command, the final examples of speaking and singing were recorded and the examination was terminated. The time course of events during the session was transcribed and analyzed.

Results

General: Right-Left Contrasts

Singing was more impaired than speech after amytal depression of the right hemisphere. Melodic deficits were characterized by striking absence of tonal control resulting in monotonic renderings of the songs. Appropriately timed changes of pitch were present as singing improved, but these were grossly inaccurate. Presumably the patients had a mental concept of the proper pitch modulations but could not properly control the necessary singing muscles. Rhythm, on the other hand, was much less affected and songs could be recognized on the basis of their musical cadence. The patients were also able to recognize the songs sung by the examiner and, in addition, hear the results of their own poor efforts. One patient, when asked how his singing sounded, replied, "Very groggy." Another complained after her performance that her "...throat feels like a watermelon."

Notwithstanding the impairment to melodic singing, speech production and language comprehension were preserved. The patients could recite the days of the week, make up novel sentences when given a key word, or answer questions such as "What day is today?" and "What is three plus five?" The patients spoke not only with clarity but also with correct phonetic pitch and stress. The only consistent deficit was a slurring of words and thickening of speech as would be seen with an intravenous dosage of amobarbital.

After left carotid injection, speech was considerably more affected than singing. At a time when only single words could be spoken, songs could be sung with clearly recognizable pitch and rhythm qualities. Although not perfect, these samples were noticeably *better* than singing at comparable times after right carotid injection. The relatively small loss in singing compared to major impairments of speech after left carotid injection stands in marked contrast to a great loss of singing and mild disturbances of speech after right injection. This dichotomy indicates that the cortical effect of sodium amobarbital is not simply a paralysis of the vocal apparatus or its neural control.

An unexpected observation was that no recognizable singing samples could be obtained before at least one word was elicited. Since the patients were mute after left carotid amobarbital injection, neither speech nor singing were heard for several minutes. However, as soon as a single word was spoken, singing rapidly improved. In contrast, speech recovery was slow, sometimes taking an additional few minutes before any more words were uttered.

Transcriptions of the testing sessions which depict protocols of the examinations following intracarotid injection are presented in Figures II-1 - II-6. The first appearances and relative rates of recovery for both singing and speech can be observed directly from the time scale. Since the sodium amobarbital had different effects on each patient, care must be taken with inter-patient comparisons.

Detailed Observations: Right Carotid Injection

Right carotid injection of sodium amobarbital produced severely deficient singing in seven of the eight patients considered in this report. Three of these, M.K., C.B., and D.M., sang upon request within the first 90 seconds of hemispheric depression, but their performances were characteristically monotonic. C.B. was allowed to use words instead of "La, la, la,..." with the result that she sang without melody but said every word correctly. It was apparent, however, that the patients had some general idea of how the melody of the songs should sound. Some would try to change the pitch of their voice at appropriate times, but would not succeed in giving a correct rendering of successive tone intervals. Rhythm, on the other hand seemed unaffected though somewhat slowed. Verbal comprehension in these three patients was excellent. Each could follow spoken instructions or answer questions with relative ease. Speech was generally intelligible and well-articulated except for some presence of dysarthria. Prosody and phonetic stress were within normal limits.

Four patients, N.F., P.E., L.H., and B.K., did not sing at all for several minutes following right amytal injection in spite of examiner's repeated requests and singing demonstrations. Two of these, N.F. and P.E., were talking and answering questions, but when asked to sing: P.E. said she could not, inappropriately remarking how nervous she had been all day; N.F. also ignored the request. (See Figures II-1 and II-3.) It was not until 2½ to 3 minutes after onset of hemiparesis before any singing could be elicited from either patient. By this time the melody was fairly good but, at the same time, voluntary movement in the paralyzed limbs was observed indicating recovery of the depressed right hemisphere.

L.H. and B.K. were neither responsive to singing nor to verbal command for several minutes. B.K. spoke her first word five minutes after amytal injection but would not sing in spite of repeated requests to do so, until an additional five minutes had passed. (See Figure II-5.) Her renditions of "Happy Birthday" and "Merry Widow Waltz," at this time, were completely devoid of melodic quality. There was little or no variation in pitch although she produced generally correct rhythmic patterns. Speech, on the other hand, had pretty well returned to normal such that B.K. was capable of maintaining a meaningful conversation, easily answering questions, and carrying out verbal commands with the non-paralyzed limbs. After another two minutes, singing fully returned to normal along with recovery from left hemiparalysis.

L.H. performed correct limb movements to verbal command but did not say her first word until four minutes after injection. Once she started to speak, however, she was able to carry on a conversation quite well. Singing was amelodic at first but slowly improved until $6\frac{1}{2}$ minutes after injection when she sang fairly well in spite of a flaccid left arm. (See Figure II-4)

The one patient, P.D., whose singing was <u>not</u> impaired after right carotid injection was strongly left-handed. Also, the usual dosage of amobarbital failed to produce complete depression of the right hemisphere as evidence by persisting movements of the left limbs. Therefore, it was difficult to draw conclusions from this session. (See Figure II-6.)

Left Carotid Injection:

Speech could not be obtained for several minutes in four of the five patients injected with amytal in the left carotid artery. It was also true that singing did not occur during the entire period of speech arrest. However in one case, P.E., concentrated attempts were being made to sing at least two minutes before similar attempts to speak. (See Figure II-3.) She made vocal attempts to mimic the examiner's demonstration of singing. This was remarkable since she exhibited no visible or audible reaction to repeated requests to say, "yes" or "hello" during the same period of time. Her "singing" improved to a level that could be vaguely recognized as a specific song, just before she was able to say her name. But it was not before she could repeat another word or two before a clearly recognizable melody was produced. Speech continued to return slowly while singing recovered more rapidly. It was not until well after her singing returned to pre-injection levels that P.E. was able to converse comfortably.

B.K. was unresponsive for an unusually long time, showing little behavior beyond wincing and withdrawing from painful stimuli. (See Figure II-5.) The first sign of recovery was repetition, upon request, of the word, "yes," $8\frac{1}{2}$ minutes after amytal injection. Almost immediately she sang two songs with clearly recognizable melody. Additional speech could not be elicited. When asked the date after singing the second song she could only mumble. In answer to another question, she said something that sounded like "seven-dovey" or perhaps, "seventy-three." She still could repeat the word, "yes," but it was a full two minutes after singing the second song before she repeated additional words on request. In fact, word repetition was all she could do for two minutes. When asked a question, she would repeat part of the question rather than answer it. It was not until 14 minutes after amytal injection or more than 5 minutes after she spoke her first word that speech approached normalcy.

It should be emphasized that speech in this patient started to return only 5 minutes after right carotid injection while attempts at singing did not appear until 10 minutes. In contrast, she sang less than 9 minutes after **left** carotid injection but did not speak a word besides, "yes," until 12 minutes after injection. Detectable signs of voluntary movement of the right limbs occurred about the time of the first signs of speech (10-12 minutes) but good control did not occur until much later. It is notable that general recovery including speech was longer after left-sided injection than after right in this patient, but recovery of singing was strikingly shorter.

No singing or speech was elicited from L.H. although her right limbs seemed strong and able to move in a coordinated manner. (See Figure II-4.) The movements were not performed either to verbal command or to demonstration even though the patient was looking at the examiner's hand. She said her first word 6½ minutes after injection and did not sing until just after that time. Her first attempt to sing was as good as her pre-examination sample which was essentially errorless. The melody was far superior to her first attempt to sing after right carotid injection and slightly better than her last attempt; the latter occurred about 6½-7 minutes after injection-- the same time as the singing sample from the left-sided injection.

The one patient who continued talking after left-sided injection was P.D., the left-hander. His singing ability was hard to assess because base-line performances were quite poor to begin with. The only evidence of asymmetry of musical performance was a lesser degree of confusion after right-sided injection, although it should be remembered that hemispheric depression had not been complete. Observations of singing in this patient hint at a reversed dominance although amobarbital testing failed to lateralize speech conclusively. Post-operative evidence confirmed that speech was controlled from the right hemisphere*.

*Others have observed the language reversal in this patient including P.J. Vogel, J.E. Bogen, R.E. Saul and myself.

M.K. (LEFT) 18 OCTOBER 1967

0:00 ONE TWO
-- THREE FOUR (INJECTION OF SODIUM AMYTAL)
-- FIVE SIX
-- SEVEN EIGHT
0:10 NINE TEN
-- ELEVEN TWELVE
-- THIRTEEN FOURTEEN
-- FIFTEEN SIXTEEN
0:20 SEVENTEEN EIGHTEEN
-- NINETEEN Keep counting. What day is today?
-- TWENTY You can stop counting. Tell us what day today is.
-- What day is it today? Can you tell us what day it is?
0:30 Marsha?.
-- MONDAY, OCTOBER SEVENTEEN How about tomorrow?
-- TUESDAY, OCTOBER EIGHT... What will tomorrow be?
0:40 TUESDAY, OCTOBER EIGHT... (COUGH)
-- That's right. Very good.
-- Okay
-- TUESDAY, OCTOBER...TOBER EIGHTEENTH
0:50 Yeah, that's right. OK. Let's try this.
-- We're going to have the singing.
-- (COUGH)
-- Okay
1:00 Okay, see if you remember the song that you sang.
-- Do you remember the song that you La-La'd first?
-- YEAH
-- La-La for me, OK?
1:10 Try and La-La for us.
-- OKAY
-- It was . . . when the saints, when the saints . . . (SPOKEN)
-- GO MARCHIN' IN (SPOKEN)
1:20 La, La, La . . . (SUNG) (S CONTINUES "WHEN THE SAINTS")
-- LA, LA, LA . . . (SUNG)
-- (NO PITCH CHANGES BUT RHYTHMICALLY RECOGNIZABLE) (E HELPS).
-- La, La, La . . . (E SUNG)
1:30 (S CONTINUES)
-- LA, LA, LA . . . (SUNG)
-- Let me try and go . . .
-- LA, LA, LA . . . (SUNG)
1:40 Let's try the continuation now, OK?
-- Listen, and you finish the song.
-- (E WHISTLING "MERRY WIDOW WALTZ")
-- (S CONTINUES SONG)
-- LA, LA, LA . . . (SUNG)
1:50 (E WHISTLING "MERRY WIDOW WALTZ)
-- (S CONTINUES)
-- LA, LA, LA . . . (SUNG)
2:00 OK, let's try one more.
-- (E WHISTLING "LA CUCU RACHA")
-- LA, LA, LA . . .
2:10
-- (S FINISHES PHRASE
-- LA, LA, LA . . .
-- Try the tapping.

N.F. (LEFT) 7 JANUARY 1969

0:00 ONE TWO
-- THREE FOUR (INJECTION OF SODIUM AMYTAL)
-- FIVE SIX
0:10 Keep counting.
-- Can you count?
-- Can you count?
-- Can you make fist with your left hand?
-- No.
0:20 Can you make a fist with your right hand?
-- Huh?
-- Can you stop counting?
-- Make a fist with your right hand.
-- Nancy. Can you make fist
0:30 with your right hand?
-- With this hand here.
-- Make a fist.
-- It's not going to do it, huh?
-- Let me ask you a question.
0:40 Can you stop counting.
-- Tell me your name.
-- Stop counting now.
-- Tell me your name Nancy.
-- Can you tell me your name?
0:50 Make a fist with your right hand.
-- Can you make a fist with your right hand?
-- (S STILL COUNTING)
-- Let's try singing a song (E STARTS TO SING "JINGLE BELLS")
1:00 Try that - sing.
-- (E SINGS: "JINGLE BELLS", ETC.)
1:10
-- (MUMBLE)
1:20 Try and sing "Jingle Bells".
-- Can you squeeze my hand?
-- That a girl. (SUBJECT DID SO WITH RIGHT HAND)
-- Can you make a fist with your left hand?
1:30 (MUMBLE)
1:40
-- CAN YOU TELL ME ONE THING?
-- (MUMBLE)
-- Now say "Methodist Episcopal".
1:50
-- METHODIST EPISCOPAL
-- Say "liquid electricity".
-- LIQUID ELECTRICITY
-- Liquid electricity.
2:00 Try it again.
-- LIQUID ELECTRICITY
-- Can you say "Seventh Day Adventist"?
-- I TOLD I WOULDN'T . . . (MUMBLE)
2:10
-- Say "Seventh Day Adventist".

C.B. (LEFT) 7 SEPTEMBER 1969

0:00 ONE TWO
-- THREE FOUR (INJECTION OF SODIUM AMYTHAL)
-- FIVE SIX
-- SEVEN EIGHT
0:10
-- NINE TEN
-- Let's see. Your left side is pretty limp now.
0:20 Make a fist with your right hand.
(S RESPONDED)
-- That a girl. Can you make a fist with your left hand?
-- Nooo . . . . Now, I'm going to say I was born in Ohio.
-- Can you say Ohio?
-- OHIO
0:30 Yeah, say Ohio again.
-- O...HI...O
-- What's . . . uh
-- What's eight times seven?
-- (FIFTY)-SIX (OR THIRTY-SIX)
0:40 Eight times seven is what?
-- (FIFTY)-SIX (OR THIRTY-SIX)
-- Yeah, that's right.
-- Now let me hear you sing "Jingle Bells".
0:50 JINGLE BELLS, JINGLE BELLS, (ETC.)
-- (S SINGS)
-- (VERY MONOTONE - MARKEDLY DIFFERENT FROM PRE-INJECTION ABILITY)
1:00
-- Uh, lift up your right hand.
-- Make a fist. (SUBJECT RESPONDED CORRECTLY TO ALL THREE COMMANDS)
-- Stick out your thumb. Can you stick your thumb.
-- Yeah, that's right. Can you do that with your left hand?
1:10 Make a fist with your left hand. Doesn't work, does it?
-- Let's try . . . uh
-- What is the day that comes after Tuesday?
-- WEDNESDAY
-- Yeah, that's right.
1:20 What's something hard?
-- Fourteen plus seven.
-- Do you know what seven plus fourteen is?
1:30
-- Say it out loud.
-- Well, let's try something else.
1:40 What is five times . .um. . six? Can you say what five times six is?
-- THIRTY
-- Yeah, that's right.
-- Let's try something else.
-- Can you sing "Yankee Doodle"?
1:50
-- YANKEE DOODLE WENT TO TOWN, (ETC.)
-- (S SINGS).
-- (FAIRLY GOOD MELODY)
2:00
-- That's pretty good.
-- Now can you make a fist with your left hand?
-- No, the other hand. (S RESPONDED WITH RIGHT HAND)
2:10 Not doing it yet, eh?
-- Can you straighten out your left leg?
-- Straighten out the right leg.
-- (S RESPONDED CORRECTLY)

Figure II-1

2:20 Let's try the tapping now.
OK?

You repeat after me.
2:30 (E TAPPING RHYTHMS)
(S TAPPING)
(E TAPPING)

NOTE: (S TAPPED ALL RHYTHMS CORRECTLY.)

2:40 (S TAPPING)
(E TAPPING)

(S TAPPING)
2:50 Do that one.
(TAPPING)
(S TAPPING)
Let me whistle one, then you tap it.
3:00
(E WHISTLING "I'VE BEEN WORKING ON THE RAILROAD")

OK, now tap it.
3:10 (S TAPPING)
OK, now hum that . . . La-La.
(S HUMMING SONG)
LA, LA, LA . . .
3:20

Now can you say very clearly
what the day . . . the day after
tomorrow is going to be?
3:30

3:40 THE DAY AFTER TOMORROW WILL BE . . .

TUESDAY, OCTOBER EIGHTEENTH
NINETEEN SIXTY-SEVEN
Today is Monday, what will the day after tommorow be?
3:50 Today is Monday. The day after tomorrow?
TUESDAY, OCTOBER EIGHTEENTH
NINETEEN SIXTY-SEVEN
What is this?
4:00 MIKE
What is that?
BALL
What did I ask you to remember?
GLASSES AND A TIE CLIP
4:10 Let's try the original thing--the waltzes again.

(E WHISTLING "MERRY WIDOW WALTZ")

4:20
Finish. (S FINISHES PHRASE)
LA, LA, LA . . .

Very good.
4:30
(E WHISTLING "MERRY WIDOW WALTZ")

LA, LA, LA . . .
4:40 Well, that's a lot better than three minutes ago.

4:50 How about this hand? (LEFT)
Can you do anything with this hand now?
Lift it up.
Yes, you c
5:00

2:20 Say "Seventh Day Adventist".

TAKE IT OUT.
Can you make a fist with your left hand?
Squeeze my fingers with your left hand.
2:30 Can you squeeze them?
CUT IT OUT.
Let's hear you say the song now.
Let's try the song.
La, La, La . . . ("HAPPY BIRTHDAY")
2:40 Can you do that?
La, La, La . . .
Can you squeeze my fingers?
Squeeze. Squeeze.
You're squeezing with the right hand
but your're not squeezing with the left hand.
2:50 Squeeze with the left hand.
CUT IT OUT. (OR PUT IT UP?)
OK What do you want up - your head?
Let me hear you sing a song.
Happy birthday to you - can you do that?
3:00 La, La, La . . . Sing the song and will be able to do it.
HAPPY BIRTHDAY TO YOU, . . . ETC.

3:10 (GOOD MELODY)

Now squeeze my fingers with your left hand. Can you squeeze them?
3:20 Squeeze my fingers.
You are moving your left arm but you aren't squeezing my fingers.
Squeeze the fingers hard.
Squeeze them with your right. (S RESPONDED)
That a girl. That's good.
3:30 Now can you squeeze with the left?
DOCTOR
WHY DON'T YOU LET ME PUT IT IN?
Do what?
3:40 WHY DON'T YOU LET ME PUT IT IN?
Put what in?
THE NEEDLE.
It's all done, it's all done.
You don't have to worry about that
3:50 part of it. It's all done.
Can you tell me what a knife and a fork are alike?
How are they alike?

How are a knife and fork alike?
4:00 A KNIFE AND FORK -
YOU CAN EAT WITH THEM. (MUMBLE)
That's right.

4:10 Now squeeze my hand with your fingers.
Squeeze my . . .
Squeeze me with the right hand.
Squeeze!
Grip hard.
4:20 How about the other one?
Can you squeeze me with the left one?
Yeah, you can squeeze me with the left one. (S RESPONDED)
That a girl. That's fine.

2:20 How about the other one?
Can you straighten the other one out?
Can you wiggle your toes?
Wiggle them all--all your toes. (S RESPONDED WITH RIGHT FOOT ONLY)
Well, your right ones are wiggling all right, but not the left ones.
2:30 Well, do you remember where I said I was born?
KANSAS
No, that was before. (IN PRELIMINARY SESSION BEFORE INJECTION OF AMYTAL)
That's not right. What did I say just now?
I said where I was born and you said after me.
2:40 Do you remember?
KANSAS
No, it was Ohio.
Make a fist with your left hand.
2:50 Can you make a fist with your left hand?
Make a fist with both hands at the same time. (S RESPONDED WITH RIGHT HAND ONLY)
Well, you did it with the right one very well,
that's very good.
Can you say "Ohio" now?
OHIO
3:00 Yeah, that's the answer.
I'm going to ask you that tomorrow.

Can you move your left arm yet?

(NO RESPONSE)

(FIRST ARM AND LEG MOVEMENT AT 4:30 - 4:50)

KEY:

Examiner's Dialogue

SUBJECT DIALOGUE

(COMMENTS)

Figure II-1 (cont.)

D.M. (LEFT) 14 JUNE 1968

0:00

(INJECTION)
ONE TWO
FOUR FIVE SIX
SEVEN EIGHT NINE
TEN ELEVEN
TWELVE THIRTEEN

0:10

FOURTEEN FIFTEEN
SIXTEEN SEVENTEEN
EIGHTEEN NINETEEN
TWENTY TWENTY-ONE

0:20

TWENTY-TWO TWENTY-THREE
(MUMBLE) TWENTY-SIX
Hold on to my hand.
Say hello.

0:30

HELLO.
Uh huh.
Can you say the days of the week? Sunday.
SUNDAY.

0:40

MONDAY.
TUESDAY.
WEDNESDAY.
THURSDAY.
FRIDAY.

0:50

SATURDAY.
What day of the week is it today?
WEDNESDAY.

1:00

(REALLY FRIDAY)
Make up a sentence that has the word "baby" in it.
MY WIFE JUST HAD A BABY.

1:10

Very good.
Can you sing La, La, La . . . Sing with me.
La, La, La . . . LA, LA, LA . . .
(S SINGS)
(S MONOTONIC - LITTLE VARIATION IN PITCH)

1:20

(BOTH E AND S SING) La, La, La . . . LA, LA, LA . . .
(S SINGS)
(AGAIN MONOTONIC - SLIGHTLY HIGHER PITCH THAN BEFORE)
LA, LA, LA . . .

1:30

La, La, La . . .
Try again.
La, La, La . . .
(E HELPS) LA, LA, LA . . .

1:40

OK now. Try something else.
Stick out your thumb. This thumb here.
(E DEMONSTRATES - RIGHT THUMB)
(SUBJECT RESPONDS (RIGHT HAND)) You did it. Very good.
Can you stick out the thumb on the other hand? (NO)

1:50

Let's try naming these gadgets.
Can you look up here? Del.
What's this thing?
What is this?

2:00

Want to feel it?
AN ERA . . .

2:10

That's right an eraser.
Can you tell what it is by looking at it?
A K..K
A KEY.

2:20

Yeah!
How about this?
What's that?

2:30

It's something people wear.
(MUMBLE) (TIE?)
Yeah, you put it on your tie.

2:40

That's right.
What's it called?
A TIE CLIP.

2:50

Yeah, very good. What's this?
A PAPER CLIP.
OK.
Now let's see you make a fist with your left hand.

3:00

Can you make a fist there?
Can't do it huh?
Can you make your left hand move at all?
No.

3:10

Can you wiggle your toes?
Wiggle your toes.
(SUBJECT RESPONDED WITH BOTH FEET)
Yeah, you wiggle them.

D.M. (RIGHT) 12 JUNE 1968

ONE TWO
THREE FOUR
FIVE SIX (INJECTION)
SEVEN EIGHT
NINE TEN
ELEVEN
Keep making a fist.
Can you keep counting?
Can you say hello?
Say hello.
Can you tell me what today is?
What is today?
What is the name of this?
Can you stick out your tongue?
Stick out your tongue.
La, La, La . . . ("JINGLE BELLS")
Can you do that?
La, La, La . . .
Can you do that? (E SINGS)
La, La, La . . . (E SINGS "JINGLE BELLS")
Can you hum?
Can you stick out your tongue?
Let me see you make a fist with your left hand.
Stick up the fist.
Can you do that?
Stick out your thumb.
Can you stick out your thumb?
Can you stick out your thumb?
On this hand? (LEFT HAND TOUCHED BY E)
Huh?
This thumb (E DEMONSTRATES GESTURE)
Can you stick out this thumb. (LEFT THUMB)
Stick out the thumb (S RESPONDS CORRECTLY WITH LEFT THUMB)
Yeah
Say hello.
Can you say hello?
Now make a fist. (S RESPONDS?)
Now stick out your thumb.
Stick out the thumb . . . like that. (E DEMONSTRATES)
That-a-babe! (S RESPONDS)
Can you say "hello" now?
Can you tell me your name?
DELBERT
DELBERT MARQUEZ
Can you say La, La, La . . .
Try that.
La, La, La . . .
Say your name again
Can you say your name again?
Del?
Say your name.
Hmmm Open up your hand
Open it up. Wide open.
Like this--see!
(E DEMONSTRATES)
Open it up.
Can you open it up?
Open up.
Open up.
Open up.
(S REACHES FOR HEAD WITH LEFT HAND)
You're not supposed to do that, remember?
GRRR. . .
Now can you say hello?
HELLO.
Yeah! Very good.
What is today?
WEDNESDAY.
Wednesday--yeah! Exactly right.
Now can you make a fist with your right hand.
Hold up your right hand.
Can you hold it up?
You aren't holding it up, huh?
Hold up your left hand.
(S RESPONDED CORRECTLY)
Yeah. That's it, hold this one up here.
Stick out your thumb.
Can you put your thumb out? (S RESPONDED CORRECTLY WITH LEFT THUMB)
Very good.
Wednesday, huh?
Now can you say the days of the week?
Try this . . . tell me what this is.
(E HOLDS UP OBJECT WHICH S DOES NOT NAME)

Figure II-2

Let's see you wiggle the fingers on your left hand.	3:20	How about that. What's that? (KEY)
		A KEY.
Can you left up your arms?		
		Yeah, good.
(SUBJECT RAISED RIGHT BUT NOT LEFT)		And that one? (ERASER)
Let's see, uh . . .		ERASER.
Try to sing with me.	3:30	Eraser, yeah.
		(HOLDS UP TIE CLIP)
Try it again.		
		(MUMBLE)
		What's that?
		(MUMBLE)
("JINGLE BELLS") La, La, La . . .	3:40	
(MORE PITCH VARIATION THAN BEFORE) LA, LA, LA . . .		(CLI . . .) (?)
La, La, La . . .		
LA, LA, LA . . .		A tie clip?
(MELODY NEARLY RECOGNIZABLE AS "JINGLE BELLS")	3:50	YEAH.
LA, LA, LA . . .		Yeah, that's what it is. It's a tie clip.
		Try this. Cup of . . .
		COFFEE.
		Yeah. Salt and . . .
	4:00	SEA.
		Yeah, knife and . . .
How does that sound to you?		(MUMBLE)
TO ME?		Heaven and . . .
Yeah.	4:10	HELL.
VERY GROGGY.		Yeah, that's right. Knife and what?
Ha, Ha, very groggy is right.		(MUMBLE)
OK.		HELL.
How about making a fist with your left hand now.		
Can you do that?	4:20	What's this? (PAPER CLIP)
(SUBJECT RESPONDED SLIGHTLY)		PAPER . . PAPER CLIP (MUMBLE)
Yeah.		Let's try singing.
		La, La, La . . .
Can you stick out your thumb?	4:30	LA, LA, LA . . . ("JUNGLE BELLS")
Stick out the thumb.		
No. Well make a fist.		
Can you make a fist?		
Well it moves, but you didn't make a fist yet.		
There's some movement there now.	4:40	
		(S SINGS WITH GOOD MELODY ONLY SLIGHTLY SLURRED COMPARED TO PRE-INJECTION ABILITY)
Let's see you stick out the little finger on your right hand.		
(SUBJECT RESPONDED)		
Yeah, that's right.	4:50	
Now can you make a fist with the left hand?		
No. That's with the right hand.		
Make a fist with the left hand.		
Not doing it yet.		
Can you say "liquid electricity" for Dr. Saul?	5:00	Very good.
Liquid electricity		Can you make a fist with your right hand?
LIQUID		
ELEC-LECT-TRIC-CITY.		Lift up your right hand--over there. (E POINTS TO RIGHT HAND)
Let's see you wiggle your toes.		Make a fist.
Can you wiggle your toes?		Can you make a fist? (SUBJECT RESPONDED)
WHICH ONES?	5:10	Yeah.
The ones on the left.		Stick out your thumb.
The left.		Stick the thumb out.
THE BIG TOE?		Now stick out the little finger.
Wiggle the toes.		Stick it up.
I MEAN, WHICH ONE DO YOU . . .	5:20	Stick up your little finger.
		It's going up. There it is.
(E CHECKS BABINSKY REFLEX - POSITIVE ON LEFT FOOT)		Very good. You did it.
		OK
		Well, I guess the test is over.
(SUBJECT WIGGLES ONE ON LEFT)	5:30	
Can you wiggle them both?		
Wiggle both toes--toes on both feet.	5:40	
(SUBJECT WIGGLED ONLY ON RIGHT ?)		
Now let's see you make a fist with the left hand.		
Make fist with the left hand.	5:50	
I'll tell you what . . .		
(SUBJECT MAKES A FIST) there it is.		
Now, stick out your thumb on that hand.		
Not quite yet.		
	6:00	

Figure II-2 (cont.)

P.E. (LEFT) 4 NOVEMBER 1970		P.E. (RIGHT) 2 NOVEMBER 1970
ONE TWO THREE (INJECTION OF SODIUM AMYTAL) FOUR FIVE Your left arm dropped down and your left leg, but your . . .	0:00	ONE TWO THREE FOUR (INJECTION OF SODIUM AMYTAL) FIVE UH . . . (CRY)
Count out loud, keep making a fist. I HAVE A STING IN MY EYE. Yeah, it'll go away in about 3 seconds. Could you say, uh . . . Yeah, your eye dropped closed.	0:10	Keep counting. Keep counting. The right arm dropped. You're not counting out loud. But the left hand continues to intermittently . . . (MOVE AROUND) That's it. 6, 7 That a girl very good.
It burns your eye doesn't it? YEAH. Uh, huh, well that's true. Make a fist with your right hand. Can you make a fist?	0:20	Right arm . . . can you You're making a fist nicely with the left hand. (A CRY - ALMOST A WAIL FROM S) Uh huh
(S DOES MAKE A FIST WITH RIGHT HAND) Yeah, that-a-girl. All right now, tell me what day is today. Can you say what day is today? (S MUMBLES) Can you say "today is Wednesday"? I KNOW IT'S WEDNES WEDNESDAY	0:30	(E SINGING "WHEN THE SAINTS . . .") La, La, La . . . Sing. (E CONTINUES "SAINTS") Can you say "yes"? (NO RESPONSE)
BUT NOT THE D-D-DATE. Uh, huh. (S MUMBLES) Let me look at your eyes a minute (S MUMBLES)	0:40	Try this. (E SINGING "HERE COMES THE BRIDE . . .") La, La, La . . .
Big pupil on that side Really big pupil on the right side. Say, uh. Can you say fifteen? FIFTEEN	0:50	Well, you're scratching your face with your left hand, but you're not singing. Can you sing? (E CONTINUES "BRIDE") Can you say "yes"? (NO RESPONSE)
Yeah, that's right. Now can you say Sing with me. (E SINGS "WHEN THE SAINTS") La, La, La . . . (S MUMBLES) I COULD (N'T) SING, I COULD . . . Let's hear you sing.	1:00	Can you . . . Try this. (E SINGS "HAPPY BIRTHDAY") La, La, La . . .
(S MUMBLES SOMETHING) NERVOUS, A CIGARETTE A what? A cigarette? Well, we can fix you up with that later on. Try this:	1:10	Can you sing? (E CONTINUES "BIRTHDAY") Can you do this? Can you do that? (E MAKES A FIST WITH HIS RIGHT HAND AND SHOWS S) Make a fist. Make a fist. Can you make a fist with the left hand? Here, see. (SHOWS FIST AGAIN)
(S MUMBLES) Uh, huh. (S MUMBLES) Hold my hand a minute. Squeeze hard. Now what I'd like to do is have you sing with me. Can you sing with me? (E SINGS "HAPPY BIRTHDAY") La, La. La . . .	1:20	Peggy make a fist. (NO RESPONSE FROM S) Big left pupil Bigger than the right Can you make . . . Can you make a fist?
Try that. (MUMBLE) I'VE BEEN NERVOUS AND SHAKING ALL MORNING. Uh huh - sing! (E CONTINUES "HAPPY BIRTHDAY")	1:30	Well, you're moving your left arm around purposefully all right. No problem about that. But, uh . . . you're moving the IV stand with it. But you're not saying anything. (IV STAND ON LEFT SIDE OF BED ABOVE HEAD) Can you say "yes"?
(S MUMBLES SOMETHING ABOUT) DRINK OF WATER I'll tell you what we'll do: we'll give you a little something to smoke and eat right after you get done but you can sing first. (S MUMBLES)	1:40	Can you make a fist with your right hand? No, flaccid Can you say? (E SINGS "HERE COMES THE BRIDE") La, La, La . . .
(E SINGS "HAPPY BIRTHDAY") La, La, La . . . Go ahead. (NO RESPONSE FROM S) Big right pupil all right. Left arm still completely flaccid.	1:50	Making a little effort, huh? (S OPENED HER MOUTH) (E CONTINUES "BRIDE") How 'bout? (E SINGS "HAPPY BIRTHDAY") La, La, La . . .
Try this: (E SINGS "MARY HAD A LITTLE LAMB") La, La, La . . . DR. BOGEN Can you sing?	2:00	Well, you're wiping your forehead well with your arm but you're not saying anything. Can you say hello? Or yes? Say "yes". Shaking your head "no"
Can you sing, Peggy? (E SINGS "MARY . . .") La, La, La . . . Sing. Would you sing?	2:10	(E SINGS "HAPPY BIRTHDAY") La, La, La . . . Try that. LA, LA, LA . . . (S TRYS TO SING) Uh huh. (S CONTINUES SINGING) (NO RECOGNIZABLE MELODY BUT RECOGNIZABLE AS SINGING)
(S TRIES A LITTLE) (E HELPS) (S MUMBLES) You said my name. Would you say your name? PEGGY.	2:20	(E HELPS SINGING) (S CONTINUES SINGING) (E HELPS) (S CONTINUES SINGING - OR MAYBE TO SPEAK, HERE)
That's right. All right, now try that. (E SINGS "HERE COMES THE BRIDE") La, La, La . . . (S SINGS "HERE COMES THE BRIDE") LA, LA, LA . . .	2:30	Try (E SINGS "HERE COMES THE BRIDE . . .") La, La, La . . . Can you do that? (E CONTINUES "BRIDE")
Keep going. (FAIRLY GOOD MELODY)	2:40	How about, uh (E SINGS "HAPPY BIRTHDAY") La, La, La . . .
WHAT I DON'T LIKE ABOUT WHEN YOUR THROAT'S . . . What's the matter with your throat? IT DOESN'T WANT . . . THE SOUNDS DON'T WANT TO COME OUT WHEN YOUR THROAT FEELS LIKE A WATERMELON.	2:50	Can you do that? (S MAY BE TRYING TO SAY SOMETHING) Can you make a fist? (WITH YOUR RIGHT HAND?) (S GROANING)
Is that right? Your throat feels like a watermelon. IS THIS . . . (LEFT HAND WAVES IN THE AIR) Make a fist with your left hand. Can you make a fist with both hands. There's movement in the left arm but no fist. There's a great fist all right. Give me	3:00	It's flaccid. (RE: RIGHT HAND) Squeeze my left hand. You're squeezing nicely with the left hand. Can you say "yes"? (S MADE NO EFFORT) (E SINGS "HAPPY BIRTHDAY")
a squeeze with your other hand. Can you give me a squeeze my left hand? IF I PUNCH ANYBODY WITH THAT FIST I'LL (REF. TO RIGHT HAND FIST) GET FINGERNAILS IN MY PALM. Yeah. I see. You better not do that, you'll cut yourself.	3:10	(S IMMEDIATELY TRIES TO SING) LA, LA, LA . . . (S RENDITION SEEMS MORE MELODIC THAN TALKING BUT THE TUNE WAS BARELY RECOGNIZABLE) Uh huh.

Figure II-3

3:20

Try "Happy Birthday". — (S CONTINUES - MORE RECOGNIZABLE AS "HAPPY BIRTHDAY")

(E SINGS "HAPPY BIRTHDAY") La, La, La . . . — (E HELPS)

Like that.

3:30 (S SINGS "HAPPY BIRTHDAY") — How about

LA, LA, LA . . — (E SINGS "WHEN THE SAINTS") La, La, La . . .

(GOOD MELODY) — (S TRIES TO SING AGAIN - BARELY RECOGNIZABLE)

LA, LA, LA . . .

3:40 How would you say "Today is Wednesday"? — (TRIES TO USE SOME WORDS)

TODAY IS WEDNESDAY.

Yeah, it's clearing up pretty well isn't it?

Can you squeeze with this hand now? — (S SEEMS TO BE TRYING TO SAY SOMETHING HERE)

3:50 (LEFT) (S NOT ABLE)

Can you raise your hands up in the air? — Can you say your name now?

Both of them. — Tell us your name.

Yes, she could. — PEGGY

(SLIGHTLY LESS WELL THAN THE RIGHT) Yes, you are raising the left one.

4:00 OH YES, I RAISED THEM A WHILE AGO AND COUNTED FOR YA. — Peggy, can you say yes?

Hmm? — YES (WEAKLY)

Can you make a fist with your right hand?

I RAISED THEM A WHILE AGO AND COUNTED FOR YA. — Squeeze my fingers. Yes, you can do it. (RIGHT HAND)

Yeah, you did it all right. — You can squeeze nicely with that hand.

4:10 OK. — That a girl. OK

I remember. — Can you wiggle the toes on your feet?

COULD I PERHAPS HAVE A TISSUE? — Can you wiggle your toes? Wiggle them on both feet.

Well, there's not much wiggle on the right.

You're wiggling the left foot nicely,

4:20 but you're not wiggling the right foot.

Wiggle the right foot.

Can you left your right hand up in the air?

Lift this one up in the air. (E TOUCHES RIGHT ARM) (S RAISES LEFT ARM)

No, that's your left hand. You're not doing . . .

4:30 The right arm is flaccid.

Can you squeeze my fingers now?

Squeeze my fingers with the right hand.

Seems to me you're not doing it. You're not doing

(S MAY BE TRYING TO TALK)

4:40 There was a little squeeze at one time.

Let me hear you say "yes" again.

(S MUMBLES SOMETHING)

Can you tell me what day it is today?

4:50 (S MUMBLES)

Can you say Monday?

Say Monday.

5:00 MONDAY

OK. That's right. It is Monday. Very good.

WHAT DID YOU . . .? (S MUMBLES)

OK, let's try singing again.

(S MUMBLES)

5:10 No, that's all right.

Now, I'll tell you what you do.

You try and sing "Monday"

Uh, try and sing again.

OK, try and sing "Happy Birthday"

5:20 La, La, La . . . (E SINGS "HAPPY BIRTHDAY")

LA, LA, LA . . (S SINGS "HAPPY BIRTHDAY" RECOGNIZABLY WELL)

5:30

Good.

5:40 Let's try.

La, La, La . . . (E SINGS "HERE COMES THE BRIDE")

LA, LA, LA . . . (S SINGS "HERE COMES THE BRIDE")

5:50

All right.

Can you say "Today is Monday"?

Try on that.

6:00 Today is Monday.

(S MUMBLES)

Can you say "My name is Peggy"?

6:10 MY NAME IS PEGGY

Try it again.

My name is Peggy.

MY NAME IS PEGGY

Very good.

6:20 OK. (S TALKING WELL AT 6:45)

Figure II-3 (cont.)

L.H. (LEFT) 4 MAY 1972		L.H. (RIGHT) 6 MAY 1972
ONE TWO (INJECTION) THREE Uh huh, keep going.	0:00	ONE TWO (INJECTION) THREE FOUR Keep going. (THE RIGHT ARM FELL DOWN
FOUR FIVE Keep going. SIX SEVEN	0:10	THE LEFT HAND IS IN A TIGHT FIST.) Can you make a fist with this hand... the right one? How about opening this hand. Can you open this hand?
Uh huh. (RIGHT HAND RAISED LEFT HAND DROPPED) Can you make a fist with your right hand?	0:20	I see you're looking right at me. Open this hand, can you open it? (S. RESPONDS.) That a girl. Make a fist. Can you make a fist?
Make a fist. Can you make a fist? You're not doing it. Make a fist. Uh huh. Can you say, "hello"? Say, "hello." Hello, hello.	0:30	Can you say, "yes"? Say, "yes." (NO RESPONSE) Can you open your hand up? Open it up wide. Now, I showed you how and you did it.
Say, "yes." Can you say, "yes"? Hmm, can you say what day today is? Not yet. (RIGHT HAND STILL RAISED) Make a fist with your right hand. Loretta, make a fist.	0:40	Okay. Open it up. See! Here, look right at me. Can you say, "yes"? Say, "yes," Loretta.
Well, you're not doing it with the right hand. (LEFT HAND IS LIMP.) Can you say, "yes," Loretta? Can you say, "yes"?	0:50	Can you make a fist? You didn't do it when I showed you how, maybe you can do it when I ask you. Can you make a fist? You're not doing it. (RIGHT ARM SLIGHTLY LIMP.)
(SLIGHT TONE IN THE RIGHT LEG AND THE LEFT LEG IS FLACCID.) Can you say, "yes"? Say, "yes." Say, "yes," Loretta.	1:00	Can you make a fist? Make a fist, Loretta, see? (EYES ARE MARKEDLY DEVIATED TO THE LEFT THE HEAD IS TURNED TO THE LEFT, THE THUMB ON THE LEFT HAND IS MOVING IN AND OUT, BUT SHE'S NOT MAKING A FIST.)
Loretta, say, "yes." Say, "yes." (OKAY, RIGHT TOES DOWN LEFT TOES VERY UP	1:10	Can you make a fist? (THE RIGHT SIDE IS STILL COMPLETELY FLACCID.) Can you say, "yes," Loretta?
LEFT HAND STILL FLACCID RIGHT HAND UP IN THE AIR.) Make a fist with your right hand. Can you sing? La, la, la...	1:20	(THE LEFT HAND IS PURPOSEFUL: PULLING AT THE SHEETS BUT NOT FOLLOWING ANY INSTRUCTIONS.) Make a fist, can you make a fist? (HEAD TURNED TO LEFT.)
Try that. (HAPPY BIRTHDAY)	1:30	Hello. Can you say, "yes," Loretta? Say, "yes."
Can you make a fist with your right hand? (CORRECT RESPONSE) Thata girl, you did it very good. Make a fist with your left hand. That's pretty limp isn't it?	1:40	(THE RIGHT LEG WITHDRAWS WHEN STIMULATED.) (S. VOIDED.) (DEFINITE RIGHT TOE SIGN, BUT THE LEFT LEG DOES NOT HAVE A TOE SIGN, IT WITHDRAWS.)
Make a fist again with your right hand, that's good. Now, can you say, "yes"? Can you say, "yes"? Say, "yes," loud. That's it. Say, "yes," out loud. I see you keep making fists over and over	1:50	Can you, ah, make a fist? Make a fist. Hello.
again with your right hand. Say, say, "yes." Can you say, "yes"? Hunh? If I pinch you will you wake up a little bit?	2:00	Can you look at me? (S. MAY HAVE HAD SEIZURE.) Look right at me. Can you say, "yes," Loretta? Can you see? (SNAPS FINGERS.) See my finger? (NO.)
Huh? OW Ow, yeah. Say, "yes." Can you say, "yes"? Can you say, "yes"? Open your hand up wide, open it all the way up.	2:10	(THE RIGHT SIDE OF THE FACE IS LIMP, THE RIGHT ARM IS CERTAINLY FLACCID.) Can you make a fist? La, la, la... (HAPPY BIRTHDAY)
(CORRECT RESPONSE) That's right, you did it. Now, make a fist. Make a fist. Make a fist with your right hand. Well, you're not doing it now. Make a fist.	2:20	Try singing. La, la, la... (HAPPY BIRTHDAY)
Can you make a... Now stick out just your thumb. (CORRECT RESPONSE) That's good, very good. Say, "yes." Can you say, "yes"? Try singing now, okay?	2:30	Or, how about Jingle Bells? La, la, la... (JINGLE BELLS)
(JINGLE BELLS) La, la, la... Can you do that? (JINGLE BELLS) La, la, la...	2:40	Hello Loretta, open your eyes. Can you say, "yes"? Say, "yes." (THE HEAD TURNED TOWARD E.) There you are, you're a little more awake.
(HAPPY BIRTHDAY) La, la, la... Can you sing that? (HAPPY BIRTHDAY) La, la, la... Well, you have your thumb out, huh?	2:50	Can you make a fist with this hand? (LEFT) Uh, make a fist. Can you make a fist? Squeeze my fingers. Squeeze hard. (WEAK FIST.)
Jingle Bells, try that. Jingle Bells, Jingle Bells, Jingle all (E. SINGING) the way. Can you do that? (JINGLE BELLS) La, la, la...	3:00	Squeeze hard. (LITTLE VERBAL COMPREHENSION, ALTHOUGH THE HANDS ARE MOVING IN A COORDINATED WAY.)
Can you say, "yes"? Huh? Can you say, "yes"? Say, "yes." Make a fist. Make a fist, Loretta. Make a fist, pull your thumb in. Make a fist. Now, open your hand. Now, open it up, open. Open the hand. That's the way.	3:10	Can you open it? Oh, a big yawn. Squeeze my hand, again. (NO.) (SING HAPPY BIRTHDAY.)

Figure II-4

Now, make a fist again. Make a fist, good, hold it. 3:20
Make a fist with this hand. (LEFT)
It's completely limp.
Stick your thumb out.
(LEFT HAND IS COMPLETELY FLACCID)
Can you stick out your thumb, your right thumb? 3:30
Stick out your thumb.
Well, you're not doing it now, huh?
Can you say, "yes," now?
There's the thumb. That a girl.
Can you say, "yes"? Huh? 3:40
Wake up, wake up. AAB
Say, "yes."
I'm going to scratch your foot again,
you tell me if you can feel it, if
you feel me scratch your foot, you 3:50
say, "ow," will ya? OW
(RIGHT TOES "DOWN")
(LEFT TOES ABOUT VERY POSITIVE)
How about saying uh, "yes."
Can you say, "uh huh"? 4:00
UH HUH. Good girl, very good.
Okay, say, "yes." Just like that, "yes."
YE E S.
SAY 4:10
YETH.
Uh huh.
YETH, THIR.
How about singing? 4:20
(JINGLE BELLS) La, la, la..
Try that.
(JINGLE BELLS) La, la, la..
Can you do that?
Can you tell me what today is? 4:30
What day is today?
TODAY IS MONDAY.
That is correct, now try la, la, la..
(HAPPY BIRTHDAY) 4:40
It's my birthday, sing me Happy Birthday.
Can you do that?
(HAPPY BIRTHDAY) La, la, la..
4:50
WHAT'S THE DATE OF YOUR BIRTH?
May 7th. It's really Thursday, my birthday.
Well, that wouldn't hurt.
Try that, try saying 5:00
(HAPPY BIRTHDAY) La, la, la..
Can you do that?
(HAPPY BIRTHDAY) La, la, la...
5:10
Can you do that?
Or sing Happy Birthday with words.
(SINGS) Happy Birthday to you.
(SOME MELODY) HAPPY BIRTHDAY TO YOU
5:20
Okay.
I FORGET HIS NAME.
Doctor Gordon - yeah, Gordon.
(SINGS) Happy Birthday to you 5:30
Happy Birthday to you
Happy Birthday Doctor Gordon
Try that, okay? Here you go.
(SPOKEN) HAPPY BIRTHDAY DOCTOR GORDON.
And, what's the end of it? 5:40
(END OF HAPPY BIRTHDAY) La, la, la...
Sing that. (SINGS) Happy Birthday to you.
Can you do that?
(SPOKEN) HAPPY BIRTHDAY TO YOU.
5:50
Tell me again what day is today?
TODAY IS ALMOST THE DATE THAT
MY HUSBAND DIED.
Is that right? 6:00
Can you make a fist with this hand?
This left hand which is absolutely,
completely flaccid.
Let's see you open the right hand.
Open it up. That's very good. You're doing it. 6:10
Make a fist, make a fist.
Uh huh, now stick out your thumb.
Stick out your thumb.
All right. Now, let's try the toes again.
OW 6:20
Oh, that was I scratched your foot,
I won't do that again.
MUMBLE HA, HA.
(THE TOE IS VERY POSITIVE.) 6:30
Yeah, your talking pretty well, huh?
If today is Monday, what is tomorrow
going to be? TUESDAY
That's absolutely right.

La, la, la.. (HAPPY BIRTHDAY)
Can you sing? Huh?
La, la, la... (HAPPY BIRTHDAY)

(S. APPEARS TO BE SOMEWHAT ALERT.)

Can you say, "La, La, La." (HAPPY BIRTHDAY)

Let's try it now, I'll give you a reward,
remember the candy.
There's a nice smile.
Do you want the candy?
Try it.
(S. SMILES EITHER TO WORD, "CANDY" OR TO E'S FACE WHICH IS CLOSE TO HERS AT THIS POINT)
La, la, la... (HAPPY BIRTHDAY)

You're starting that's it.
La, la, la... (HAPPY BIRTHDAY)

(THE RIGHT ARM IS STILL FLACCID.)
Give me a squeeze.
Huh, can you squeeze it.
Can you do this?
Huh, open the hand up. (NO RESPONSE.)
Can you sing?
La, la, la... (JINGLE BELLS)
Remember the candy?
That's a girl, look at the candy now.
La, la, la... (JINGLE BELLS)
Can you do that?
OOH...
La, la, la... (JINGLE BELLS)
Okay.
Hm, hm, hm... (HAPPY BIRTHDAY)
OOH...
AAH...

Hm, hm, hm... (HAPPY BIRTHDAY)
AH, SHA, SHA...
Can you make a fist?
Make a fist with both hands.
Make a fist with both hands.
(RIGHT HAND STILL FLACCID.)

Loretta, can you tell me your name?
Loretta, say, "Loretta."

Loretta, it's a nice smile. (PROBABLY RESPONDING TO E.'S VOICE AND EXPRESSION.)
Loretta, can you say, "yes"?
Can you say, "yes"?
Can you say, "yes"?
Can you say, "yes," Loretta?
Say, "yes."
Well, you patted my cheek very nicely,
but you're certainly not saying yes.
Would you like, like to be nice to me,
huh?
Would you like to be nice to me?
Sure you would, let me hear you sing.
La, la, la... (JINGLE BELLS)
If you wanna be nice to me, that's the way.
La, la, la... (HAPPY BIRTHDAY)
(RIGHT ARM IS NOW MOVING SPONTANEOUSLY.)
OWH (YELP.) (E. SCRATCHES BOTTOM OF FOOT.)
(LEFT FOOT NOW WITHDRAWS AND THE
RIGHT TOE IS NOW DOWN.)

Figure II-4 (cont.)

We got a minute left for some singing.	6:40	Can you make a fist with both hands?
Nothing wrong with that. All right now let's try.	--	While I'm showing ya, make a fist.
(HAPPY BIRTHDAY) La, la, la..	--	Both hands.
	--	You opened your left hand up wide.
Can you do that? You haven't done it yet.	--	I LOVE YOU.
(HAPPY BIRTHDAY) LA, LA, LA...	6:50	
	--	Oh, but you didn't sing.
	--	You can't love me very much.
	--	Can you sing now?
	--	Sing.
(FAIR MELODY, BUT NOT GOOD)	7:00	La, la, la... (HAPPY BIRTHDAY)
	--	Go ahead.
	--	I
	--	LOVE (TO THE TUNE OF HAPPY BIRTHDAY.) (GOOD MELODY.)
HAPPY BIRTHDAY DOCTOR GORDON.	--	
	7:10	YOU
Well, thank you very much.	--	
Okay, well your right hand is.	--	TO YOU
I'LL EVEN BUY YOU A PRESENT.	--	I
The left hand is quite	--	
You're going to buy him a present.	7:20	LOVE
YEAH. You can sing Happy Birthday to me	--	YOU
on Wednesday, that'll make my present,	--	TO YOU
the best present he ever had if you	--	
sing Happy Birthday to him on Wednesday.	--	I
That's right. Okay, well, now then um...	7:30	LOVE
Can you wriggle your toes?	--	
That's fine.	--	YOU
Can you wiggle the left ones?	--	All right.
Wiggle the left ones.	--	
No, wiggle on the left.	7:40	
Wiggle the right ones again.	--	
Wiggle your right toes.	--	
You're not doing it.	--	
Wiggle your toes.	--	
Wiggle your toes.	7:50	
Left ones, she's doing it.	--	
Can you see something there?	--	
Wiggle your toes, Loretta.	--	
There goes the left ones.	--	
Okay, now then, can you make a fist	8:00	
with this hand?	--	
(RIGHT) Squeeze my hand.	--	
Make a fist with both hands as hard	--	
as you can.	--	
Make a fist.	8:10	
OH, I'D LOVE TO SQUEEZE YOUR HAND.	--	
Oh, give it a squeeze then.	--	
Here, squeeze this. (LEFT HAND)	--	
That a girl.	--	
Okay, now squeeze it with the other	8:20	
one. You're not doing it yet. (RIGHT HAND)	--	
Well, uh... How about Jingle Bells?	--	
(JINGLE BELLS) La, la, la..	--	
Try that.	--	
JINGLE BELLS	8:30	
(FAIRLY GOOD MELODY) JINGLE BELLS	--	
JINGLE ALL THE WAY	--	
OH WHAT FUN IT IS TO RIDE	--	
IN A ONE HORSE OPEN SLEIGH	8:40	
Great.	--	
That's the best I ever heard you singing.	--	
I think we are about done aren't we?	--	

Figure II-4 (cont.)

B.K. (LEFT) 15 SEPTEMBER, 1972		B. K. (RIGHT) 18 SEPTEMBER, 1972
(INJECTION) ONE TWO	0:00	ONE TWO, (INJECTION)
THREE FOUR	—	THREE FOUR
FIVE SIX	—	FIVE SIX.
SEVEN EIGHT	—	Keep counting.
Nine Ten	0:10	(BOTH HANDS DROPPED DOWN AND BOTH FEET DROPPED DOWN.) (SIGH)
Can you keep going?	—	
(RIGHT HAND) Your hand is going, but I don't hear you talking.	—	Can you count any?
SIGH (HEAVY BREATHING)	—	Can you say anything?
Keep moving your hand That's very good.	0:20	Have you stopped breathing Mrs. K --? Are you breathing?
Keep making fists with both hands.	—	
The right hand is making a fist but not the left hand.	—	(MOMENTARY RESPIRATORY ARREST.)
Can you say, "yes"?	0:30	Now, you're breathing.
Mrs. K --	—	
Can you say, "yes"?	—	
Can you say, "yes"?	—	
Can you stick out your tongue?	—	(FLACCID ALL OVER)
Stick out your tongue, Mrs. K --	0:40	How about a little painful stimulation?
(LEFT LEG FALLS, RIGHT REMAINS STRONG)	—	Are you going to respond to that at all?
(UH)	—	(NO.)
Can you stick out your tongue Mrs. K --?	—	
Stick out your tongue.	0:50	
(EYES DEVIATED TO THE RIGHT)	—	
Hello, Mrs. K -- Hello	—	(BOTH PUPILS ARE EQUAL AND THE EYES ARE DEVIATED MARKEDLY TO THE LEFT.)
Can you say, "yes"?	—	
Can you say, "yes"?	—	
Stick out your tongue.	1:00	How about a little pinch in the trapezius?
Well your right hand is still going back and forth.	—	(SLIGHT QUIVER IN THE LEFT SIDE OF THE FACE.)
Can you open your right hand?	—	
Open up your hand Mrs. K --	1:10	How about rubbing the sternum?
Open your hand	—	Hello there.
Open it up	—	Are you starting to wake up a little?
No, you're still making a fist back and forth.	—	(NO.)
Can you wiggle your toes?	1:20	Can you move your left arm up in the air?
Wiggle your toes.	—	How about this?
Hello. Can you open your eyes?	—	Can you do something with this left arm? (BOTH ARMS FLACCID.)
Would a little pinch help you to wake up a little bit?	—	
(RIGHT SIDE OF THE FACE WINCED)	1:30	(PINCHING THE LEFT TRAPEZIUS GIVES WINCING ON THE LEFT SIDE OF THE FACE BUT NOT ON THE RIGHT SIDE.)
Stick out your tongue.	—	
(A TRAPEZIUS PINCH ON THE LEFT SIDE PRODUCES A LITTLE BIT OF WINCE ON THE RIGHT.)	—	How about in the toes here?
All right, well let's see you stick out your tongue, Mrs. K --	1:40	
Can you stick out your tongue?	—	
Huh, stick out your tongue.	—	(POSITIVE TOE SIGN ON THE RIGHT.)
	1:50	
(THE EYES ARE STILL DEVIATED TO THE RIGHT.)	—	(NOTHING ON THE LEFT.)
What have you got squeezed there with the right hand?	2:00	
Boy, you got a good grip on the right hand.	—	
Can you let go? Let go.	—	
You just keep on squeezing.	—	
You're not cooperating here.	2:10	(SLIGHT TOE SIGN ON THE LEFT.)
Could you let go with this hand?	—	
(POSSIBLE TRACTION RESPONSE)	—	(THE LEFT THUMB MOVED SLIGHTLY.)
There now you let go.	—	(NO TOE SIGN ON THE LEFT AND A LITTLE BIT OF ONE ON THE RIGHT MOSTLY FLACCID ALL OVER THERE.)
Now if you put a little traction it closes right up again.	2:20	
(RIGHT LEG NOT FLOPPED OVER. RIGHT HAND IS WELL COORDINATED, HOLDING ONTO THE SIDE OF THE BED. THE EYES ARE NO LONGER DEVIATED.)	—	Can you move this hand? (LEFT) Give us a squeeze over here with the left hand. (FLACCID)
	2:30	(MAY HAVE BEEN A LITTLE MOTION.)
Can you stick out your tongue Mrs. K --?	—	
(COORDINATED MOTIONS OF THE RIGHT HAND, BUT NO SPEECH.)	—	
(THE RIGHT LEG HAS GOT SOME TONE, THE LEFT LEG HAS NONE.)	2:40	
(THE RIGHT ARM IS MOVING WELL.)	—	(THE LEFT HAND MOVES WHEN THE TRAPEZIUS IS PINCHED.)
Can you do anything with this arm? (LEFT)	—	
(NO, IT'S COMPLETELY FLACCID ON THE LEFT.)	2:50	(LEFT HAND MAKES PINCHING MOTION.)
How about a "Happy Birthday"?	—	Squeeze my hand.
Can you say, "Happy Birthday"?	—	(PINCHED THE TRAPEZIUS.)
(SINGS) Happy Birthday to you.	—	(LEFT HAND MAKES A PINCH.)
La, la, la..]	—	
Mrs. K--, how about that?	3:00	
La, la, la...]	—	
Moving your mouth.	—	
(HAPPY BIRTHDAY) La, la, la..]	—	(LITTLE TONE IN THE LEFT ARM.)
	3:10	Now I'm going to rub your sternum.
	—	Well, you're making a fist in the left hand.
	—	Now, what if I pinched the trapezius?

Figure II-5

(SAINTS) La, la; la...	3:20	Can you make a pinch for us?
		Hunh? (LEFT HAND MAKES PINCH MOTION.)
		Yeah.
Let's try it a little slower tempo.		Now, you're starting to move a little.
(HAPPY BIRTHDAY) La, la, la...		
	3:30	(THE EYES ARE STILL MARKEDLY DEVIATED TO THE LEFT.)
		Can you move this leg?
		How about moving this one?
		Can you move it? (NOTHING.)
(RIGHT HAND CONTINUALLY MOVING.)	3:40	How about giving me a squeeze with this hand?
		Can you squeeze it?
		Can you do anything?
		Can you say, "hello"?
I think I have the wrong melody now myself.	3:50	Can you stick out your tongue?
How about Happy Birthday?		Stick your tongue out.
(HAPPY BIRTHDAY) La, la, la...		(EYES ARE STARTING TO SWING OVER TO THE RIGHT.)
		(THE WINCE IS STILL MARKEDLY ASYMMETRICAL, BUT IT IS PRESENT ON THE RIGHT SIDE.)
	4:00	Can you do something this (LEFT HAND)
Happy Birthday.		Mrs. K --?
Wake up and say, "hello".		Give me a squeeze.
Can you say something Mrs. K--?	4:10	How about this one.
Bernice Say, "yes."		Can you squeeze it?
Can you say, "yes"?		Yeah, now you're squeezing with the left hand.
Huh?		Okay, now that's it.
Can you say, "yes"?	4:20	Let go with the left hand.
Can you say, "ha"?		Let go with it.
Say, "ah..."		Can you let go?
Ah...		Let go.
Can you say, "ah"?		No, she's doing rhythmic movements.
That's a little easier than saying yes.	4:30	Now squeeze -- hard.
Can you open your eyes?		(NO RESPONSE TO VERBAL COMMAND.)
Open your eyes.		
Make a fist over here with your right hand.		
	4:40	Let's see what happens if we rub the sternum.
Now open it up, open it up.		
Keept it open, keep it open.		(GROAN) (HEAVY BREATHING)
(KEEPS MAKING FISTS AND OPENING.)		(MAKES A FIST ON THE LEFT.)
Keep it open.		
Well, you got a good fist there, but you aren't keeping it open.	4:50	
Can you keep it closed?		
Keep your fist closed.		Can you move your feet?
Keep it closed.		Let's see you wiggle your toes.
Now, no, no, keep it closed.	5:00	(NO.)
How about the left one?		
Can you make a fist over here with the left one?		
(COMPLETELY LIMP)		
How about saying, "yes"? "Yes?"		
Can you say, "yes"? Huh? Say, "yes."	5:10	
YES		
There's a "yes."		(POSITIVE RIGHT TOE SIGN NOTHING ON THE LEFT.)
Say it again, say, "yes."		
YEAH That a girl.	5:20	
Can you stick out your tongue?		
(TRYING UNSUCCESSFULLY)		(WITHDRAWAL OF THE LEFT LEG.)
Can you say, "today"?	5:30	Can you move a little bit of something?
		What can you move?
Can you say, "la, la, la"?		Can you stick out your tongue?
LA		La, la, la... (MERRY WIDOW WALTZ)
LA	5:40	
All right now try		
(HAPPY BIRTHDAY) La, la, la.		
(HEAVY BREATHING)		
(HAPPY BIRTHDAY) La, la, la.		
	5:50	
Can you open your eyes?		Come on, wake up.
Open your eyes.		Wake up, Bernice.
(SHE SEEMS TO BE GOING TO SLEEP.)		Stick out your tongue.
Can you raise up your hand?		Say, "yes."
Raise up your hand. GROAN	6:00	Can you say, "yes"?
Keep it open.		Can you say, "yes"?
Keep your hand open.		Can you lift your arm up?
		(RIGHT ARM VERY FLACCID)
GROAN		How about this one?
Now squeeze my fingers.	6:10	Can you lift this one up?
Give it a good squeeze, squeeze it.		Can you do anything with your left side?
Hold it, hold it.		(LEFT ARM NOT RESPONDING.)
GROAN		(BILATERAL WINCE IN THE FACE AND WRIGGLE IN THE LEFT FOOT AND MOVING THE LEFT HAND.)
You're squeezing rhythmically, but you're not holding, hold it, hold it. GROAN	6:20	
Can you make a fist with your other hand?		Give me a squeeze.
Maybe she's singing.		Here, I'll hold on here.
Okay let's try that.		Now, you squeeze my fingers.
(HAPPY BIRTHDAY) La, la, la...		You're not doing it.
OOOH	6:30	You were doing it before.
(HAPPY BIRTHDAY) La, la, la...		Can you squeeze that?
OOOH		
(HAPPY BIRTHDAY) La, la, la...	6:40	La, la, la... (MERRY WIDOW WALTZ)
OOOH		
(SODIUM AMYTAL SEEMED TO PUT HER TO SLEEP.)		
Can she say her name?		
Bernice	6:50	How about Jennifer, can you sing about Jennifer?
Say, "Bernice."		
Say, "Bernice."		La, la, la... (HAPPY BIRTHDAY)
Can you say, "Bernice"?		
Bernice Wake up Bernice.		

Figure II-5 (cont.)

BERNICE	7:00	
There you go, very good.	—	Bernice, can you stick out your tongue?
Now, can you say, "yes"?	—	
YES	—	Open your eyes Bernice.
Uh huh, wake up a little bit now.	—	Open 'em up.
That a girl, don't go to sleep with the	7:10	
sodium amytal.	—	
Uh huh, say, "yes." YES	—	
Say, "today." TODAY	—	
Say, "today is Friday."	7:20	(EYES ARE DEVIATED TO THE LEFT.)
TODAY IS FRI	—	
Say it again a little louder,	—	(PUPILS ARE NORMAL.)
"Today is Friday."	—	
TODAY IS FRIDAY.	7:30	(THE FACE IS NOW WINCING SYMMETRICALLY.)
That's good now make a fist with both hands.	—	
Make a fist. Make a good fist.	—	Can you move your right arm Bernice?
Make a good fist now.	—	(VERY FLACCID.)
You're not doing it with either one.	7:40	(BOTH LEGS FLACCID.)
That's a good one, with the right one make	—	You really are limp.
a fist. Hold the fist with the right one.	—	
How about the left one, can you make a fist	—	
over here with this completely flaccid arm?	—	You're not even doing anything with the left hand now.
YES, YES DOCTOR.	7:50	
Okay, make a fist now. Hold my fingers.	—	Can you do anything with this left hand?
Don't let go. Don't let go. Hold it.	—	
ALL RIGHT SIR.	—	Give me a squeeze.
No, you're doing very weak.	8:00	Can you say, "yes"?
Hold on tight. Now open it up.	—	La, la, la... (MERRY WIDOW WALTZ)
MUMBLE	—	
Open your hand, open it up.	—	(FACE IS SYMMETRICAL ARMS NOW ARE SYMMETRICALLY LIMP.)
Open it up. That a girl.	—	
Very good, open it all the way.	8:10	
MUMBLE	—	
Open it up all the way, that's fine.	—	
Can you open the other one? Open the other one.	—	
How about wiggling your toes?	—	
Wiggle your toes. Just the right ones.	8:20	(POSITIVE LEFT TOE SIGN.)
Can you wiggle the left ones?	—	(WINCES WHEN RIGHT FOOT IS SCRATCHED.)
Wiggle all your toes.	—	
MUMBLE	—	
That's pretty good though, you wiggled more.	8:30	(WITHDRAWS LEFT FOOT A BIT.) (SLIGHT WITHDRAWAL.)
Can you stick your thumb out on this hand?	—	
Stick out your right thumb. Nope.	—	
Doesn't seem to work very well, does it?	—	
Now, why is it you're able to follow a	—	There you are.
verbal request to wiggle your toes	8:40	Can you say, "yes," now?
when you can't do the left side at all?	—	YES
Why is that? STUPID	—	That a girl, just like that.
Can you wiggle your left toes?	—	La, la, la... (MERRY WIDOW WALTZ)
(HEAVY BREATHING)	—	
No, that's the right toes.	8:50	
Let's see you make a fist.	—	Sing.
Make a fist. You're going to sleep.	—	LA, LA, LA... (MERRY WIDOW WALTZ)
Wake up.	—	
That's it make a fist.	—	
Make a fist on both hands.	9:00	
Can you make a fist on the other hand?	—	(RECOGNIZABLE MELODY.)
I'LL TRY. You can try.	—	
MUMBLE	—	
Can you tell us what three plus four is?	9:10	
SEVEN That's right.	—	
How about five plus two?	—	How about Happy Birthday?
What's five plus two?	—	La, la, la... (HAPPY BIRTHDAY)
SS SEVEN	—	Try that.
That's right.	9:20	
Now wake up a little bit.	—	LA, LA, LA... (HAPPY BIRTHDAY)
I've got a hard one for you.	—	
How much is five plus eight?	—	
FF Uh huh.	9:30	(RECOGNIZABLE MELODY.)
THIRTEEN (OR) (FIFTEEN) (?)	—	
How many? THIRTEEN	—	
Thirteen is correct.	—	
Now, can you sing Happy Birthday?	9:40	What day is today?
Sing, "la, la, la..."	—	What day is today?
(HAPPY BIRTHDAY)	—	
OOOH Go ahead. YOU	—	
YOUR MAKING YOURSELF SUFFER.	—	What day of the week?
We'll suffer, just sing.	9:50	? LOVAVOVEY?
Go ahead.	—	What's two plus two?
(HAPPY BIRTHDAY) La, la, la...	—	NNH - YES.
WELL I'LL DO IT FOR FOR A HAPPY BIRTHDAY.	—	Huh?
For Jennifer. FOR MY DOLL	10:00	What's two plus two?
Yeah. HAPPY BIRTHDAY	—	
(MORE SPOKEN THAN SUNG) HAPPY BIRTHDAY	—	SEVEN - DOVEY
HAPPY BIRTHDAY	10:10	No, it's not seventy-three, no.
DEAR JENNIFER	—	Can you say, "yes"?
HAPPY BIRTHDAY TO PRINCESS	—	Say, "yes."
HAPPY BIRTHDAY	—	YES
How about uh...	10:20	What month is it?
Would Jennifer like to hear you sing the	—	THE SEVENTH
saints? She might.	—	No, September.
(SAINTS) La, la, la...	—	Can you say, "September"?
I HARDLY THINK SO DOCTOR.	—	Say, "September."
How about... How about the "Merry Widow Waltz."	10:30	SEVEN - LOVIN
Let's try that.	—	Can you say, "one, two, three"?
La, la, la... Go ahead.	—	SEVEN
LA, LA, LA...	—	DOLLAR No, no, no.
(SINGS MERRY WIDOW WALTZ.)	10:40	Say, "one, two, three."
(POOR MELODY)	—	SEVEN - LOVEY
(MELODY DETERIORATES)	—	LOVIN - OOL -
La, la, la... LA, LA, LA...	—	SEVEN
	10:50	DOLLAR
La, la, la... LA, LA, LA...	—	How 'bout the Saints?
	—	La, la, la... (SAINTS)
La, la, la... LA, LA, LA...	—	(AVEY)

Figure II-5 (cont.)

Can you say, "Today is September the fifteenth"?
"Friday, September the fifteenth"?
I'LL TRY IT. Uh huh.
TODAY IS FRIDAY,
SEPTEMBER THE FIFTEENTH.
You're absolutely right.
What day will tomorrow be?
FIFTEEN IT WILL BE.
IT WILL BE UH AUGUST?
It's still going to be September tommorrow.
SEPTEMBER
I'M SORRY.
What day is it tomorrow?
What day of the week?
SATURDAY,
SEPTEMBER THE SIXTEENTH.
You're absolutely right.
Now, can you make a fist with both hands?
Make a fist with both hands.
Yes, you are moving the left one now very well.
Make a real tight fist over here. Fair.
Now, let's see you move the toes on both feet.
Wiggle 'em. There they go.
(BOTH WIGGLE.)
Would you like to have us take the needle out and have a little something to drink?
IT DOESN'T MATTER DOCTOR.
I'M JUST FINE.
Okay, sing Happy Birthday and then we're all done.
I'M JUST VERY THIRSTY.
We're going to give you a drink of water here in about three minutes.
You sing Happy Birthday.
OOH
WHY DO YOU PUNISH YOURSELF DOCTOR?
Because we like the pain.
Now. Happy Birthday (SINGS) to you.
(SINGS) HAPPY BIRTHDAY TO YOU
HAPPY BIRTHDAY TO YOU
Good.
HAPPY BIRTHDAY DEAR JENNIFER
HAPPY BIRTHDAY TO YOU
Good. TO YOU
We are now going to pull out the needle and I have to press on your neck so it won't bleed and that hurts a little bit.
THAT'SALL RIGHTDOCTOR,
YOU BEEN VERY KIND.
We're going to press on there.
I don't think you'll like the pressing, nobody does.
YOU'VE BEEN VERY NICE. THANK YOU.
Yes ma'am, you're a super, super patient.

11:00 How about that?
La, la, la... (SAINTS)
No?
Give me a squeeze.
Can you squeeze here?
11:10 The right arm is still kind of limp, isn't it?
How about this one?
Let me see you wiggle your toes Bernice.
Wiggle.
11:20 You wiggle in the left ones.
Oh, there's a little wiggle on the right one.
Yeah, not nearly as good as the left.
Let me see you make a fist.
Make a fist.
11:30 No, that's just the left hand.
Make a fist with both hands.
Make a fist with both hands.
Now, open your hand up. Open up.
Open, open, open, open.
11:40 You're not opening.
Make a fist, tight fist.
Make a fist.
You're sticking your thumb out in the left hand there.
I don't think you got your instructions straight.
11:50 Give me a squeeze.
That's a good squeeze with the left hand.
Now, you have to let go.
Squeeze with the right hand.
(SLIGHT GRIP ON THE RIGHT HAND FOR THE FIRST TIME.)
12:00 There's a little grip.
Let me see you wiggle your toes again.
Wake up and wiggle your toes.
Wiggle your toes.
Say, "yes." YES
12:10 Say, "September." SEPTEMBER
That's quite good.
What year is it? SEPTEMBER
That's what month it is.
12:20 What year? NOVEMBER
No, what year is it?
1999? No.
It's 197_?
What?
12:30 197_? I - - DON'T KNOW
Can you say, "two"?
Say, "two." TWO
Yeah.
Now say, "1972."
12:40 19--
72
Well, that's pretty good.
What's two plus two.
12:50 Can you tell us what two plus two is?
TWO
PLUS
TWO Yes, what is that?
13:00 I'M SORRY - -
- -THAT I DIDN'T - - MUMBLE?
If you add two and two, what do you get?
13:10 TWO AND TWO Yeah.
Two and two?
13:20 TWO AND TWO
Is?
Are?
Two and two equals what?
TWO AND TWO Yeah.
13:30 - - INE
ARE
What's the name of this town we're in?
Where are we?
13:40 Can you tell us where we are? CALIFORNIA
That's the state, what's the city?
OH, I'M SORRY.
UH UH
13:50 What city. UH
Do you know the name of the hospital?
YES.
UM MUM MEMORIAL?
14:00 That's pretty good.
What's my name? DOCTOR BOGEN.
That's pretty good.
What's your name? BERNICE K--
What month is it?
14:10 SEPTEMBER SIXTEENTH.
Yeah, what, uh, what year?
Can you tell me what year it is?
YES, I WILL.
14:20 UH
UMM
UH
14:30 I'M SORRY.
Can you say, "1972"?
1972
Can you give me a grip now with this hand? (RIGHT.)
Squeeze it with the right hand.
14:40 Now let go.
Let go.
Open up both hands.
Open up both hands all the way, that's good.
14:50 Now make a fist with both hands.
Make a fist.
Now stick out the thumb on both hands.
Can you stick out the thumb?
You're not sticking out the thumb on the right hand yet.
15:00 Ah, there it is.
Not so good.
Well, you haven't recovered there yet, have you?
Do the Saints there.
La, la, la... (SAINTS)
15:10 LA, LA, LA... (SAINTS)
OOH, MY VOICE.
15:20 That's great.
15:30

Figure II-5 (cont.)

P.D. (LEFT) 23 OCTOBER 1969		P.D. (RIGHT) 17 OCTOBER 1969
ONE TWO	0:00	ONE
THREE FOUR	--	THREE FOUR (INJECTION OF SODIUM AMYTAL)
(INJECTION OF SODIUM AMYTAL) FIVE SIX	--	FIVE.
SEVEN EIGHT	0:10	Keep counting.
NINE	--	Can you count?
	--	Can you count?
Can you make fist?	--	Say six, seven.
Make a fist.	--	No! He is just breathing deeply.
Can you make a fist?	0:20	The right leg went down all right.
Neither leg went down and the	--	Can you make a fist with this hand?
arms both lack some tone.	--	Make a fist with your left hand.
Can you make a fist with this?	--	You're holding it up in the air nicely.
(E SHOWS HAND) Can you make a fist?	--	Can you make a fist with it?
	0:30	Can you make a fist with your . . . (S RESPONDED WITH LEFT HAND)
(E SHOWS FIST) Watch my hand.	--	That's the idea. Let's see you stick out your little finger.
Phillip! Can you say "yes"?	--	Stick out your little finger.
YES	--	No. Can you say yes?
	--	YES
Make a fist with this hand. Make a fist.	0:40	Very good.
Can you make a fist?	--	
(NO) Make a fist.	--	Can you tell me what day today is?
Can you do what I'm doing?	--	FRIDAY
(E CONTINUES TO SHOW FIST) See what I'm doing.	--	OCTOBER.
Make a fist. Make a fist. (S RESPONDS)	0:50	SEVENTEENTH
That's it, good.	--	OK Let's try "London Bridge".
Can you do this? See.	--	La, La, La . . . (E STARTS TO SING)
Look right at my hand.	--	LA, LA, LA . . . (S SINGS)
Can you do this?	--	
Can you look at my hand? Here it is do that.	1:00	
Can you sing La, La, La . . . Try that. ("LONDON BRIDGE")	--	(MELODY ALMOST AS GOOD AS BEFORE INJECTION)
LA, LA, LA . . .	--	
	--	That's all right
(S CONTINUES SONG WITH FAIRLY GOOD MELODY)	1:10	La, La, La . . . (E SINGS AGAIN "LONDON BRIDGE")
	--	Like that.
What day is today Phillip?	--	LA, LA, LA . . . (S CONTINUES AS BEFORE)
Can you say what day today is?	1:20	La, La, La . . .
It is . . .	--	
Can you say "yes"?	--	
YES	--	
Can you say "No"?	--	LA, LA, LA . . .
NO.	1:30	HOW DOES IT GO?
Can you say what today is?	--	Well, you did pretty well.
TODAY IS FRIDAY.	--	Can you make a fist with your right hand?
Where was Dr. Gordon born?	--	Your left leg just fell down.
	--	Can you make a fist with the left hand?
	1:40	Stick out your left little finger.
		Can you stick out your left little finger?
ILLINOIS.	--	NO, I DON'T . . . (MUMBLE)
Very good.	--	Try it. Stick out your left little finger.
Let's see you make a fist in each hand.	--	Open up your left hand.
Can you make fist?	--	Can you open it up?
(S RESPONDED)	1:50	Open it up all of the way. Open it up. (S RESPONDED)
Now stick out your thumbs.	--	Now make a fist again.
Stick out your thumbs.	--	Make a fist.
You are moving your left fist very well	--	Make a fist with your left hand.
but not sticking out the thumb.	--	DR. BOX - HOW'S THAT
Can you stick out your thumb?	2:00	(MUMBLE)
Let's see you put both hands down.	--	
You did. You put both of them down.	--	Can you remember where Dr. Gordon was born?
OK	--	. . .

Figure II-6

(NOTE: NEVER A DEFINITE PARALYSIS ON LEFT SIDE)	2:10	Where was I born? (DR. G.)
	--	PHILADELPHIA (S'S BIRTHPLACE)
	--	PENNSYLVANIA
	--	I wasn't born in Philadelphia
Can you sing again Phillip?	2:20	Pennsylvania (DR. G.)
	--	Where was I born? (DR. G.)
	--	Come on, I told you where I was born. (DR. G.)
	--	Where was I born? (DR. GORDON MOVES INTO S'S VIEW)
La, La, La . . .	--	OH. IN ILLINOIS
(E STARTS "LONDON BRIDGE")	2:30	That's good.
LA, LA, LA . . .	--	I'm going to tell you where I was born.
.	--	See if you can remember it tomorrow.
.	--	I was born in Ohio.
(S SINGS "LONDON BRIDGE")	2:40	Can you say Ohio?
	--	OHIO
OK. Thank you.	--	Yeah, very good.
	--	Now, can you make a fist with this hand?
	--	With your right hand?
	2:50	Make a fist with your right hand. (S RESPONDED CORRECTLY)
	--	Yes, you made a fist with your right hand.
	--	Make fist with this hand. (LEFT)
	--	Can you make a fist with both hands?
	--	Make a fist with both hands.
	--	Can you make a fist with this hand?
	3:00	You've got good tone in that arm all right.
	--	Make a fist.
	--	Make a fist with this hand. (RIGHT) (S RESPONDS CORRECTLY)
	--	Can you stick out your little finger?
	3:10	Like this. Stick out both little fingers. (E DEMONSTRATES)
	--	Can you stick out your little finger?
	--	You stuck it out on the left one.
	--	And now on the right.
	--	Very good - OK
	3:20	
	3:30	
	3:40	
	--	Can you say . . .
	--	Say "yes" again.
	--	YES
	--	Yeah. You don't have any trouble with that.
	3:50	Let's try "London Bridge" again.
	--	LA, LA, LA . . . (S STARTS TO SING)
	--	La, La, La . . . (E HELPS)
	--	COULD YOU TELL ME HOW IT GOES?
	4:00	Yeah, La, La, La . . .
	--	Try that.
	--	LA, LA, LA . . .
	4:10	(S SINGS ALONE WITH GOOD MELODY)
	--	Try "Happy Birthday".
	--	La, La, La . . . (E STARTS "HAPPY BIRTHDAY")
	--	LA, LA, LA . . .
	4:20	(S CONTINUES "HAPPY BIRTHDAY")
	--	(S STOPS)
	--	La, La, La . . . (E HELPS)
	4:30	Can you do that?
	--	LA, LA, LA . . .
	--	(S CONTINUES "HAPPY BIRTHDAY")
	4:40	You got the rhythm pretty good I'd say.

Figure II-6 (cont.)

Discussion

The most notable finding was that singing was more impaired than speech when the right hemisphere was depressed but less impaired than speech after left hemisphere depression. A similar left-right dissociation between the two functions has been implied in previous case studies but none have been able to exclude the possibility of functional compensation by the intact hemisphere between the time of injury and the time of tests. Furthermore, only a few accounts have compared musical ability before and after cerebral injury. The present study avoids both of these weaknesses. The singing dysfunction is measured in the present patients before, during, and after a "reversible hemispherectomy" where typical symptoms of unilateral hemispheric ablation are temporarily induced only to fully disappear some minutes later. Consequently, direct comparisons of the performance of one hemisphere can be compared to the normal functioning of both, in the same individual. Not only does the rapid reversal of symptomatic hemispherectomy render the question of functional transfer to be meaningless, but also provides critical "pre-injury" data.

Therefore, we can confidently assert from our observations that these patients normally depend more upon their right hemisphere for the tonal qualities of singing than upon their left hemisphere. This is particularly meaningful because these individuals (except P.D.) have a well-established left hemispheric dominance for speech, not only on the basis of the amytal studies, but also on the basis of testing following cerebral commissurotomy.

It must be emphasized that the major deficit in singing after right carotid injection was the production of the correct pitch. Rhythm was hardly affected at a time when singing was either monotonic or markedly off-key. Rhythm was also not affected after left hemispheric depression which, in this case, was in accord with the relatively good quality of singing. It is apparent, therefore, that the ability to produce rhythm for singing is a function that can be equally well mediated by functions in either the left or right hemisphere alone, whether or not there exists the ability to sing on pitch. This finding is supportive of an hypothesis put forth in Section I that the reason there were no ear differences in melody recognition in the dichotic listening task was that the distinctive cues may have been rhythmic rather than tonal. It was the chords stimuli, devoid of rhythmic or temporal quality, which showed the left ear dominance, thereby indicating a superior performance by the right hemisphere. Milner also found perception of rhythm was not affected by either a left or a right temporal lobectomy(9).

Whereas tonal control was the characteristic deficiency of singing after right carotid amobarbital injection, there was no evidence of similar tonal defects in speech. Patients did not speak in a monotone but rather maintained natural voice inflections in spite of some disturbance from dysarthria associated with the systemic distribution of the barbituate. It is concluded that pitch control for singing is not only a function separate from the control of speech-pitch, but that it is represented in the right hemisphere while tone control of language is represented in the left. This conclusion is consistent with the view that dysprosody of speech is a variant of aphasia typically associated with left hemisphere lesions(20,21).

The present findings are contrary to the general belief of early reviewers(22,23) who thought speech and singing were both lateralized to the left hemisphere. This view followed from the concept that the left hemisphere was dominant overall while the right was only an extra or reserve organ. The modern idea is that each hemisphere is differentially dominant for complimentary capacities(24, 25,26,27,28).

We can now add pitch control for singing and recognition of chords to the list of cognitive abilities for which the right hemisphere is dominant. It is difficult to see how these musical aspects can be called, "spatial," in the same sense that an object or pattern has length and breadth. Yet these general facets are better perceived by the right hemisphere. However, if the word, "spatial," can be understood as "having no time dimension," then a direct parallel between auditory and visual or tactual modalities can be made. The change in terminology simply shifts the emphasis from the right hemisphere's analyzing objects in space to analyzing them as whole, non-temporal entities. Conversely, the left hemisphere's analysis of objects has been shown to require a sequencing or ordering as has been demonstrated for some auditory(29), visual(30,31) and tactual(32) stimuli. The simultaneous-sequential idea is not new(33) but it has not yet been associated with auditory stimuli. Our data indicate that time may be of the essence in describing asymmetries of cerebral function--the left hemisphere being marked with its presence and the right hemisphere characterized by its absence.

III. VERBAL AND NON-VERBAL AUDITORY INVESTIGATIONS IN PATIENTS WITH MAJOR BRAIN SURGERY

A. Musical Abilities after Hemispherectomy.

Introduction

It is well-known that cerebral damage incurred in childhood is far less incapacitating than comparable damage acquired by adults. The usual explanation is that the brain is still plastic at an early age and apparently capable of functional reorganization(1). Severe trauma and disease to one hemisphere in children causes normally lateralized functions, such as speech or spatial orientation, to be transferred from the damaged brain to be squeezed together with the functions of the intact hemisphere. This is demonstrated when the specialized functions of a diseased hemisphere are retained even if the hemisphere must later be surgically removed(2,3). Had the functions not transferred or had they only partially transferred, they would have been lost or severely impaired after surgery. The age at which cerebral plasticity becomes minimally active or non-operable has not been established. A common idea is that the critical stage cannot be fixed decisively and is a chronological continuum, the upper limit of which is puberty(1).

Adult patients have a far worse prognosis for recovery from behavioral deficits caused by severe trauma and brain damage incurred after age 18. The question of plasticity in this regard is still open. "Spontaneous" recovery within the first few months after trauma may well reflect a subsidence of diaschisis; long term recovery, due to relearning by other cortical areas or to transfer of function to the opposite side, is probably less frequent(4). With regard to aphasia, handedness and degree of language lateralization may be a significant factor(5). Adult cases of complete hemispherectomy so far reported have been documented to have some symptomatic recovery in functions usually lateralized to their excised hemisphere. Dominant (left) hemispherectomy cases will have minimal recovery of speech(6,7,8) and non-dominant cases will have limited ability in visual ideational, spatial, and other non-verbal tests(9). Conversely, cases of non-dominant hemispherectomy are generally unimpaired in verbal skills, while in one case of a left hemispherectomy, spatial and musical functions were much less affected than verbal functions(10). It is clear that strict lateralization to the left hemisphere for language or to the right for spatial qualities and music is not an acceptable model. The problem is a matter of degree where a cognitive ability may be laterally specialized in one hemisphere and not in the other, but is never completely absent in the less dominant side.

A grey area of uncertainty encompasses the degree of lateral specialization in a partially mature brain. With reference to aphasia, the relatively few reports of childhood trauma do not have clear conclusions regarding recovery(1). In these cases, the reasons for and the mechanisms behind functional recompensation or interhemispheric transfer simply cannot be determined. Very few reports exist on hemispherectomies in children whose cerebral damage occurred later than infancy. Two cases were reported by Gardner _et al_.(11): One was a 9-year-old right-handed female who could talk without evidence of impairment. Learning took place after her operation; attention and mental integration improved. The other patient was left-handed and had a left hemispherectomy at age 10. Aphasia had accompanied initial seizure activity that occurred one year before the operation, but speech was relatively intact post-operatively except for persistent evidence of anomia and alexia. The only other case report is of a boy who showed first neurological signs at age 14(12). A malignant glioma was removed but its recurrence resulted in a left hemispherectomy. The patient regained excellent language comprehension contrasting to a relatively slow speech recovery. He was cheerful and alert and reportedly enjoyed music immensely. Language expression seemed to have reached a plateau of recovery.

The present study is a report of observations on two young hemispherectomy cases, one left and one right. These patients are extensively studied by a number of investigators in the areas of language, memory, and other cognitive functions(13,14,15,16). The present study was limited to observations of music and singing which has been shown in the previous Section of this Thesis to have special representation in the non-dominant cerebral hemisphere.

Observations

Right Hemispherectomy

The first subject, D.W.(seen through the courtesy of I.G. Gill of San Marino, is an adolescent male(age 15) who had undergone removal of the right hemisphere by Dr. J. Green of Phoenix at age 7 because of acute encephalitis. The surgical excision included all of the cortex but spared the basal ganglia. Prior to the operation the patient was left-handed; but intracarotid injection of sodium amobarbital before surgery indicated speech lateralization in the left hemisphere. At present, the patient is ambulatory, talks well, and goes to school. He cannot voluntarily move his left arm but has use of his left leg; he can walk rapidly and manage stairs with relative ease.

The Seashore Test of Musical Abilites(17) was administered to this patient in one session. The test battery consists of 6 subtests of musical aspects such as Tonal Memory, Timbre, and Rhythm. The results revealed a severe deficit in each section of the test. The patient not only scored poorer than average, compared with a standard of normal school children of grades 6-8, but actually failed to reach a level higher than could have been attained by chance guessing. Two exceptions were the subtests measuring Timbre and Loudness where scores were still subnormal but above chance level. The patient's performance on this test can be compared to a group of patients with temporal lobe excisions(18). Those who had left temporal removal showed little impairment but those with right lobectomies were significantly deficient on most of the subtests, especially Timbre and Tonal Memory. Nevertheless, they were consistently better than the present patient and considerably above a level of chance guessing.

The hemispherectomy patient returned for three additional sessions in which only the Pitch and Loudness subtests were repeated. The test method was changed so that the stimuli could be channeled through stereo headphones instead of a loudspeaker. The third test session differed from the first two in that the test stimuli were reconstructed so that they would be easier to discriminate. Results showed that performance on the Pitch Test still remained at chance level in each session including the one with simplified discriminanda. In fact, further informal testing showed that this patient could not consistently distinguish the difference between two tones that differed by as much as one full musical step. This evidence supports the hypothesis that the left hemisphere is a poor discriminator of pitch and that the right is needed for this task.

Pitch was tested more directly by use of a toy xylophone. Only four tone-bars (C,E,G,B) in the same octave were used; all others were removed. The examiner struck one of the bars with a plastic mallet out of view of the patient. The response was simply to find and play the same tone. D.W.'s performance on this task was variable. Most of the time he would hit the wrong bar but claim it was the same as the one he had heard. When questioned, he would usually insist his choice was correct while smiling as if the examiner were trying to talk him out of a correct decision. Surprisingly, the patient could perform the same task with only a few errors in a minority of trial runs, only to fail in a second try. Apparently, there are cues which provide the patient with enough information to perform the task, but at a threshold level so that performance may deteriorate with any distraction or drop in motivation.

Singing in this patient was poor. When he would try to hum along with familiar songs on the radio, the melody would have only a vague resemblance to the correct version. Solo renditions of songs that he knew or with which he was more familiar were also sung quite poorly although they were not unrecognizeable. A better performance was elicited when he was allowed to sing the simplest of songs such as "Happy Birthday" or "Jingle Bells."

The specific ability to hear and sing pitches was tested in two ways. In the first, the patient was required to listen to two successive pure tones taken from the Pitch subtest of the Seashore battery. The pitches comprised an interval of approximately one-quarter tone and it was the patient's task to sing the two tones exactly as he heard them. The result was a failure. While occasionally he was close to the correct pitches, most of the time the interval was far from accurate or he sung the low pitch first when he should have sung the high, or the high pitch when he should have sung the low. The test was repeated in a second session but instead of the Seashore stimuli the experimenter sang the demonstration tones which were comprised of intervals greater than one-quarter of a musical step. In this version, the patient sang much better, always reproducing the high and low tones in the correct order, and more closely approximating the proper pitches.

Rhythm, in contrast to melody, was generally well-reproduced. At a time when D.W. was singing songs with his usual poor melody, the rhythm of the song was sung essentially without error. He could also tap his hand in rhythm to well-know songs, but was more imprecise with songs of which he was less familiar. He could imitate short, simple rhythms tapped by the examiner as long as they were relatively slow. Fast songs and fast rhythms resulted in failure, but it was unclear whether this was a musical defect or purely a motor one.

D.W.'s deficits in singing are in sharp contrast to speech. The patient is very verbal, talks freely, and seems to have no trouble expressing himself. There are no obvious aphasic deficits. Perhaps the best way to characterize this patient is that he is a poor singer. He exhibits all the symptoms of being "tone deaf" since he can hear only the large pitch differences and sing only the most well-known songs. Of course, it is true that one could not predict how this patient would perform had he not had cerebral difficulties although the patient claims that he never could sing very well. But it is clear that singing and musical ability are far inferior to speech and language ability, and that he is functioning with only the left, dominant hemisphere.

Left Hemispherectomy

R.S.(seen through the courtesy of Dr. J.E. Bogen of Los Angeles) is a 12-year-old female who had undergone surgical removal of a malignancy in the left cerebral hemisphere at age 8. A recurrence of the tumor required subsequent excision of the complete left hemisphere two years later by Prof. P.J. Vogel of Los Angeles. The second operation reportedly had little effect on the patient's speech although the evidence is anecdotal and was not tested directly. She has since had subsequent operations to install and adjust a ventricular-jugular shunt to aid fluid evacuation of the surgical cavity which has had retarding effects on her ability to speak well.

Her general health is good except that she is severely handicapped with hemiplegia and homonymous hemianopia. She is alert and active and particularly likes to swim. Her disposition is warm and friendly and she seems to love company. However, she tends to act silly at times and her teacher has reported that she can be a behavioral problem in class.

Speech comprehension has improved since her last operation and is presently quite good, more than two years after hemispherectomy. She appears to understand most of all that is said to her including complicated syntactic instructions such as "Put an X on the picture which shows what we sleep in," or "Draw a cat under the table"(14). However, verbal expression is still severely impaired. She can minimally read and write and has a mediocre ability to name objects or colors although she can recognize the correct names when spoken to her.

In contrast to speech, R.S. exhibits excellent singing ability. Her parents report that she has always enjoyed singing and that her ability apparently has not changed as a result of any of her surgical ordeals. A tape recording was made of several songs sung by the patient three weeks after her dominant hemispherectomy(19). She sang songs such as "Yankee Doodle," "Jingle Bells," and a complicated Hawaiian song with excellent melody and remarkable clarity. In addition, R.S. sang each song complete with the lyrics while speech at this time was limited to single words and short phrases.

Recent testing reveals no significant changes in her singing ability. Her parents have reported that she has learned new songs from the radio or from activities with her peer groups. Several songs are among the patient's repertoire which are sung melodically and rhythmically correct and, as before, complete with words. In contrast, when she is asked to repeat the words of a song without singing the melody, she has a difficult time and typically fails after a phrase or two. If she is coaxed to try again, she can often repeat one or two lines and then have to repeat the song silently to herself in order to be able to continue where she had left off. There are some exceptions when she can manage to recite the whole text of a song at one time.

The Seashore Test of Musical Abilities could not be administered to the patient in a normal way because she could not seem to grasp the instructions. Instead, only the Pitch Test was presented. The test consisted of two pure tones which were played in succession. Rather than decide whether the second of the tones is higher or lower as dictated by the normal method of presentation, she was simply asked to sing the two pitches. Not surprisingly, she performed the task with remarkable ability even though the interval between the pitches was only one-quarter of a musical tone.

In a similar test where the stimulus pitches were sung by the examiner but with intervals greater than one-quarter tone, the patient again responded with an excellent performance. However, when three individual pitches were sung as stimuli, the patient had difficulty in remembering each of them even when the intervals were as great as a musical third. Her memory impairment was not specific to music, however, as it was evident throughout all testing.

The xylophone test was presented in the same manner as with D.W. The examiner played one of four tone-bars with a plastic mallet out of the patient's sight. The required response was to find the same tone. During the first part of the test, the patient obtained excellent scores, hitting each tone accurately or, if she made a mistake, finding the correct tone on the second try. But as the test progressed she became steadily worse. It was still apparent that after each wrong tone she knew her mistake, but she would hesitate before making a second choice, and then would play the same tone she had just decided was wrong. Other times she would choose the wrong tone altogether. It is possible that she was confusing her own wrong response with the stimulus or that the summation of tone stimuli from trial upon trial was interfering with her performance. Another factor was her memory problem. In the xylophone test, it was found that if she were required to wait 10-15 seconds before she tried to find the correct tone-bar, her performance would drop.

In contrast to the previous patient, it is known that R.S. could sing prior to the first appearance of malignancy. But it is notable that with the lack of development of good speech, singing has remained as excellent as ever. Again, the hypothesis that the right hemisphere is critical for certain musical function is supported. Just as language needs an intact left hemisphere for expression so do certain aspects of music need a good right hemisphere.

B. Functional Deficits following Partial Surgical Division of the Forebrain Commissures in Man as Determined by an Auditory Test.

Introduction

Extensive testing has been carried out on two patients in whom a partial surgical division of the forebrain commissures has been made leaving intact the posterior-most part of the corpus callosum. The surgery, undertaken for relief of intractible epilepsy, was less extensive than in previously reported patients by Sperry and others (20,21,22,23) in the hope that the therapeutic benefits would be sustained but that the severe cerebral disconnection symptoms would be avoided. Up to now the worthwhile analeptic effects have persisted and, as expected, these patients show a remarkable paucity of the typical behavioral deficits found in the usual, more complete split-brain cases(24). In particular, these patients can easily cross-match objects felt in one hand and retrieved with the other; they can pair pictures between the left and right visual half-fields; and they can match pictures or written word-names with objects in any visual field-retrieval hand combination--all in striking contrast to the previous brain-bisected cases who have had the more complete forebrain commissurotomy. Subtle shapes and forms such as jigsaw puzzle pieces and bent wire forms were also found to be transmitted from one side of the brain to the other through the splenial portion of the callosum.

The same high level of interhemispheric communication was found to prevail also in the auditory modality. That is, these patients responded more like normal controls than like the patients with complete commissure section, exhibiting no more unusual left-right asymmetry than normals in routine auditory testing. However, an abnormal oddity did appear in these auditory tests. When separate verbal messages were presented to left and right ears, they seemed to get mixed together in a peculiar way: Instead of being reported successively as in normal subjects, a brief message presented to one ear together with another message in the other ear were instead reported as a jumbled mixture. Typically a word or two would be reported from one ear, then some words from the other ear, and then back again to the first. The normal way is report from one ear and then the other. It was hypothesized that some filtering or inhibiting system through the callosum had been severed by the partial commissure surgery in these patients, thereby preventing the more normal, separate, and successive processing of the two inputs. Both inputs became combined into a single jumbled piece of information. The present study sought to accentuate this odd jumbling effect and to assess the possible changes in the auditory system caused by the partial surgical division.

Verbal information from the left ear most likely gets to the left speech hemisphere from the right side via the corpus callosum. The ipsilateral route is generally found to be the weaker(25) and less important in dichotic listening studies(26,27). The hypothesis that prompted the present study predicts the existence of some pathway that would normally pass through the anterior callosum and have the effect of separating, attenuating, or even briefly blocking interhemispheric transmission of information. (See Figure III-1.)

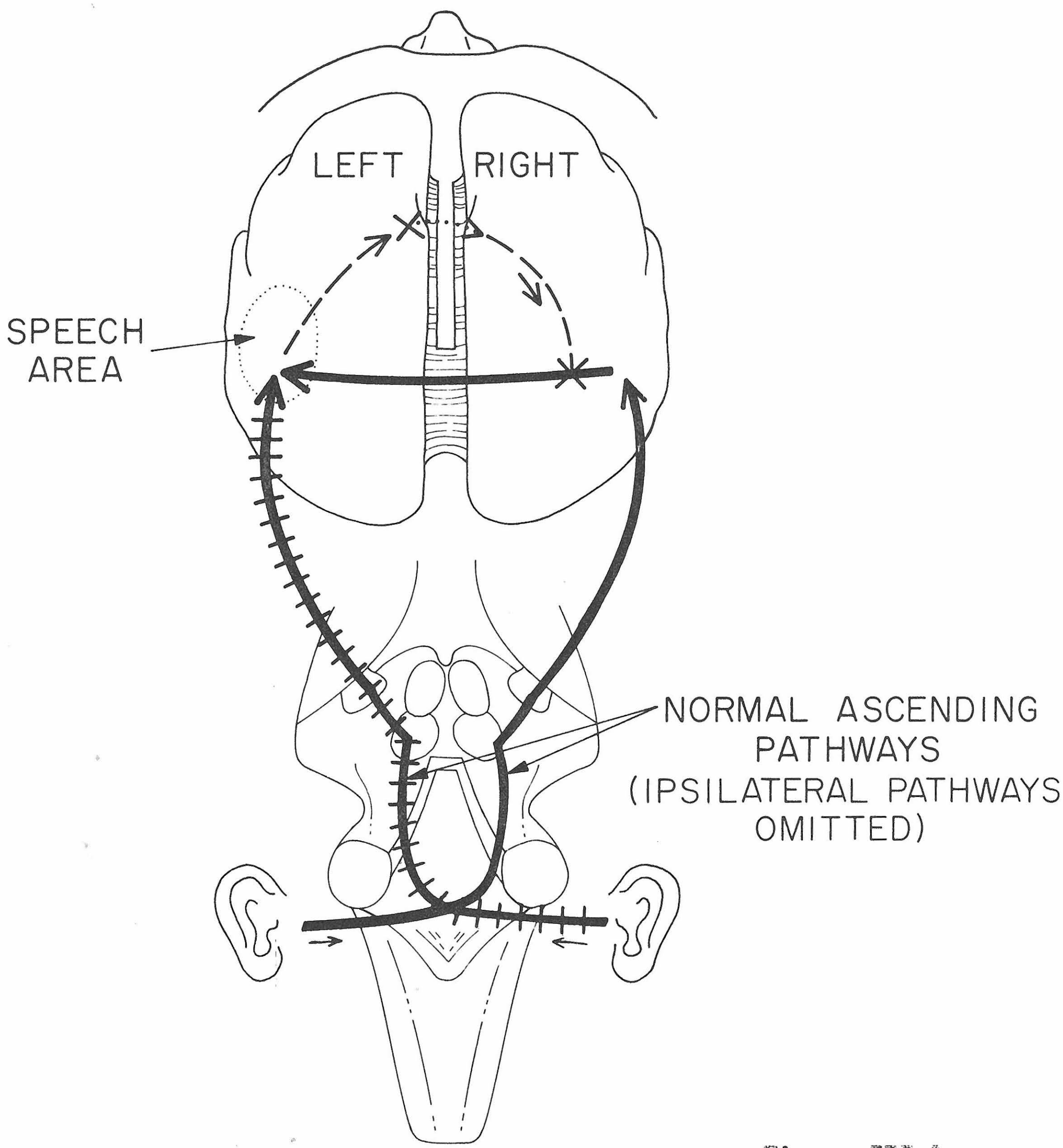
LEFT
RIGHT
SPEECH AREA
NORMAL ASCENDING PATHWAYS (IPSILATERAL PATHWAYS OMITTED)

Figure III-1

The hypothesis was tested by introducing meaningful stimuli into one ear and then noting the amount of disturbance that is caused by a distraction to the other. In other words, we were simply testing the subject's ability to ignore irrelevant and distracting stimuli arriving in one ear, and to attend to meaningful and task-dependent stimuli in the other ear. The prediction was that the two patients with partial commissure section would be poor at this task compared to normal controls.

Methods

The stimulus information was a long list of simple words which was presented to one ear. The subject was required to repeat each word of the list as he heard it. That is, the subject had to listen to the first word, and then quickly repeat it before he heard the second word, and so on, until the end of the word list. If he left out words or mispronounced them, he simply went on to the next word rather than lag behind. The rate of presentation increased until the subject simply could not keep up with the words.

The distraction stimulus in the other ear was a delayed feedback of the subject's own voice as he repeated the words of the list. As each word was spoken, it was recorded on audio tape and then played back about 200 milliseconds later. This voice delay has been shown to be quite disconcerting for most people(28) as evidenced by several obvious speech defects. In this test, only gross mispronunciations and substituted or omitted words were counted as incorrect, while minor distortions were accepted.

The experimental design was relatively simple. The word list input goes into one ear and, as the subject repeats each word, a delay is introduced and the result is heard in the opposite ear. The test was presented with the stimulus words in the left ear with the delayed feedback in the right ear, and then presented again in the reversed situation. The left-right order of ear presentation was changed from session to session and from subject to subject.

The set-up so far described allows measurement of the subject's ability to concentrate on one ear while the other is being distracted. In order to measure maximal confusion that delayed feedback is capable of producing in these subjects, another experimental condition was designed as a control. In this situation, both the word list and the delay went into both ears. In contrast to the test situation, the control condition provided both ears with the word list and also with the delayed feedback so that the effect of the distraction could not be avoided by attentional shifts from ear to ear.

Results

The results reflect a basic difference between the patterns of performance for the two patients with partial commissurotomy as compared with performance patterns for a normal control group. The difference was that the partial section patients made maximal percentages of errors not only when the delayed feedback was presented to both ears together but also when presented to only one ear alone. In contrast, the normal controls had the greatest percentage of errors only when the delayed feedback was in both ears but not when in either one alone. It also appears that the disturbance for the left ear was not equivalent to that of the right in either of these two subject groups. There were more errors in the condition where the stimulus words were presented to the left ear and delayed feedback was heard in the right, than the other way around. In other words, the subjects were better able to repeat words presented to their right ear than presented to their left. The right ear dominance effect is just what one would expect based on similar findings with ear competition in dichotic listening tasks.

A second control group consisted of four unoperated epileptics whose seizure activity was controlled by medication. No brain damage has been found for any subjects in this group, although at least two(S.N. and J.B.) had more than the usual level of sedation as measured by blood levels. The dosages of medication were: K.L., 400 mgm diphenylhydantoin (DPH) and 225 mgm phenobarbitone(ØB); S.N., 250 mgm DPH, 195 mgm ØB, and 1800 mgm tridione; J.B. 260 mgm ØB; R.L. 200 mgm DPH, and 1 gm Peganone. The performance for this group fell somewhere between the patients with partial commissurotomy and normal controls. The group performed faster, in general, than the operated subjects, but slower than normals. Whereas there is some evidence that epileptics with less severe, diffuse brain damage will have decreased response times(43), these control patients have increased response times which is attributed to their medication.

The maximal effect of delayed feedback was found for binaural presentation but not significantly worse than monaural feedback to either ear. It can be seen from Figure III-2 that the epileptic control group

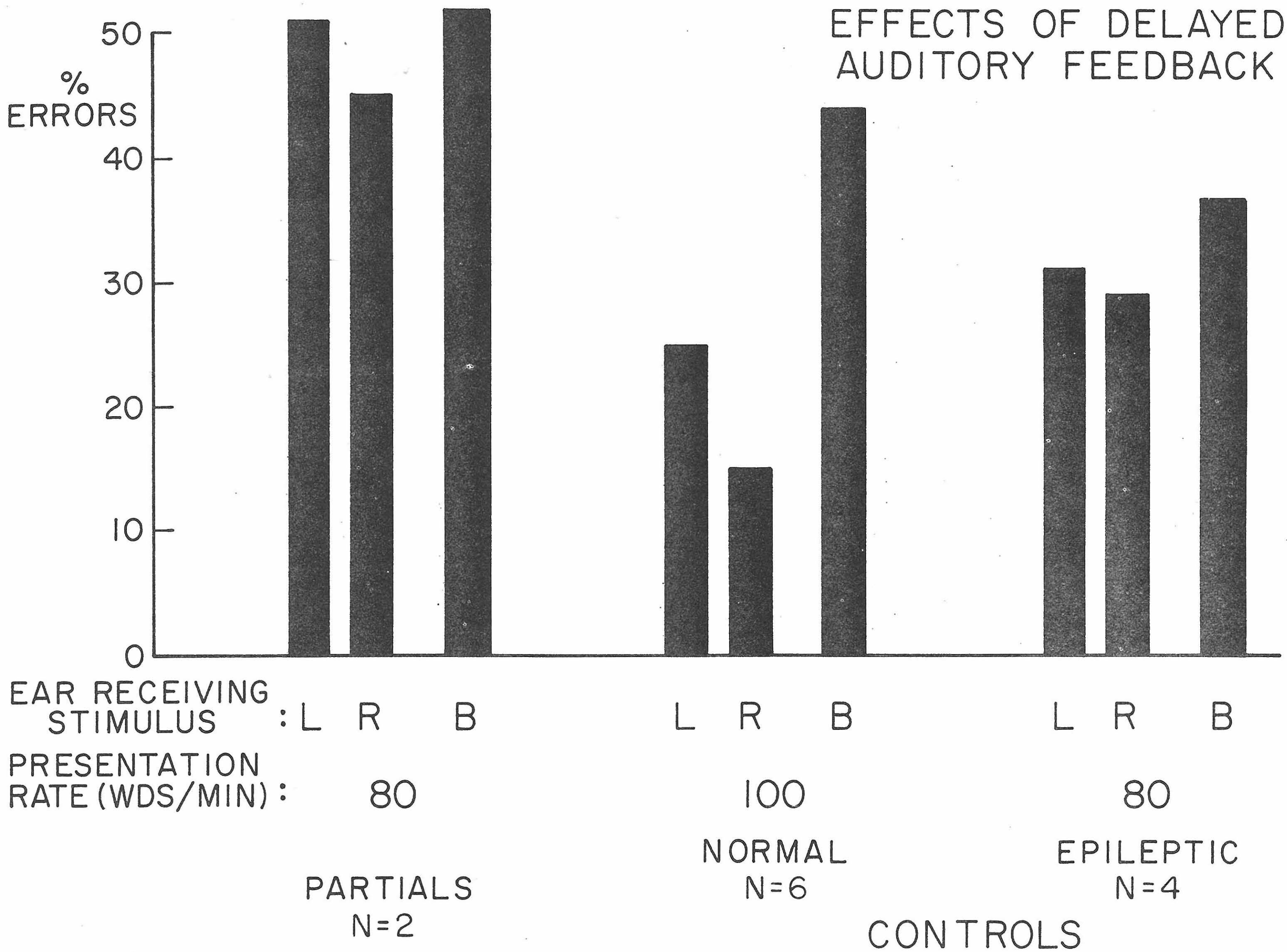
EFFECTS OF DELAYED AUDITORY FEEDBACK
% ERRORS
50
40
30
20
10
0
EAR RECEIVING STIMULUS : L R B L R B L R B
PRESENTATION RATE (WDS/MIN) : 80 100 80
PARTIALS N=2
NORMAL N=6
EPILEPTIC N=4
CONTROLS

Figure III-compared more favorably to the surgical group than to normal controls in spite of the slight trend towards a greater binaural disturbance as was present in the normal group. The results suggest that the effects opserved for the partial commissurotomy cases may be due to the epileptic condition or to the medication but not to the surgery. If this should be so, then audition can be included in the already exhaustive list of non-symptomatic findings for partial disconnection of the corpus callosum.

It appears that these data fail to support the hypothesis set forth in the introduction to this study--namely, partial surgical division of the cerebral commissures causes a jumbling effect for the two ears. One would first have to discount the confounding results from the epileptic controls. While it is recognized that an attempt to do so requires undue caution, some unusual raw data provides some impetus for at least a further look.

Scores for the delayed feedback tests were compared against other scores obtained for tests in which there was no delayed feedback. For the partials, the non-delayed feedback tests were always easier to perform, whatever the presentation rate of the word list. For both control groups, however, a surprising phenomenon occurred. At the fastest presentation rates--faster than the partials were capable of attaining--and when bilateral feedback was present, some subjects actually performed as well as, and in some cases, better than when there was no feedback at all! In other words, these subjects performed best in the one task that should have been the most difficult. It is most likely that this observation is explained by an artifact of the test technique and, more particularly, of the scoring method. One subject claimed that he was staggering his responses so that he could arrange to have the feedback be heard at times that would have the least effect for him. If he is correct in his self-evaluation, and if the reduction of errors in bilateral delay conditions is due to a conscious or unconscious effort to control the speed of the responses, the results for these subjects may not reflect the intended effect of the delayed feedback phenomenon, but rather a sophisticated response scheme. Although members of both control groups showed this effect, the critical presentation rates were different; the epileptics showed the effects earlier because their overall reaction times were slower. The fact that a better score is obtained for the binaural delay condition at the faster presentation rates is precisely the opposite of what we had expected to happen. It is possible to test in future experiments the validity of these confounding results by presenting the stimulus list at a variable rate so that the subject could not easily space his responses and thereby minimize the delayed feedback effect. Also, reaction times, instead of accuracy scores, could be used to measure the degree of distractibility.

If the control data for the epileptics can be discounted, then comparison of the data for the partial commissurotomies with those for the normal controls supports the hypothesized model. That is, the surgical patients are distracted with delayed feedback in only one ear because there is some lack of interhemispheric inhibition that normally acts to keep separate the information initially arriving in each of the two hemispheres.

C. Verbal Processes in the Right Hemisphere of Cerebrum-separated Patients as Determined by Tests of Dichotic Listening.

Introduction

Two groups of neurological patients are most ideal for investigating the right hemisphere language capabilities since direct influence of the left hemisphere can be avoided. The first are those who have had severe damage to the dominant hemisphere as adults which has subsequently led to surgical removal of the entire brain half. Several such cases have been reported(3,6,8,9) in which the general finding is that relatively small but not zero speech recovery is observed, while language comprehension is much less affected. The best example of language development after dominant hemispherectomy is a case reported by Smith and others(7,10). In this patient, a tumor was first observed and then removed at age 45. The left hemisphere was removed two years later when the malignancy recurred. Speech recovery was slow, but after a few months the patient was able to repeat simple words and utter common expletives such as "ouch" or "damn", and automatic one- and two-word phrases like, "Well, I..." After a year he improved to the point where he could initiate complete sentences of his own creation. Comprehension appeared to be markedly better than speech. The right hemisphere apparently has some restorative power for language.

The second group of patients in whom language studies can be made are those whose left hemisphere has been surgically separated from their right as a last-resort treatment for intractible epilepsy (29). These patients are unique in that each hemisphere is independently capable of its own data processing and characteristic behavior. Separate observation of the non-dominant hemisphere allows direct study of its language capacity.

As a rule, speech could not be elicited(30), although there have been some claims to the contrary(31,32). In contrast, comprehension has been confirmed in the right hemisphere although the limits are still being determined. Concrete nouns were the most readily understood as evidence by correct object matching to the corresponding word-names or even to complex definitions(33). Another study showed that in a tactual object-to-word matching technique, adjectives could also be recognized(34). However, a visual test could not demonstrate comprehension of verbs(35). This task required the subject to pantomime an action indicated by a printed verb flashed at 0.1 second to the left visual field (and therefore to the right hemisphere) or to point to an appropriate picture depicting the particular action. The conclusion from failures on these tests was that verbs were beyond the language capacity of the minor hemisphere. The present observations indicate this conclusion may have been premature and that the right hemisphere can at least comprehend verbs presented vocally.

The auditory pathway from one ear projects to both the contralateral and ipsilateral hemisphere. Of the two, the contralateral route has been shown to be the more dominant by a number of reports with both physiological(25,36,37) and behavioral(26,38,39) evidence. The superiority of the contralateral pathway is also reflected in the ear competition arrangement of dichotic listening where asymmetrical performance of stimulus recognition is found favoring the ear opposite the dominating hemisphere. For example, if verbal stimuli are presented simultaneously to each ear, the right ear out-performs the left; if musical chords are the stimuli, the left ear out-performs the right. In each case the hemisphere opposite to the superior ear was specialized for that task. (See Section I)

In studies with cerebrum-sectioned patients, the contralateral pathway is not only dominant but appears to block information arriving from the ipsilateral route during dichotic listening tasks. Consequently, the behavioral effect is that the right ear almost exclusively projects to the left hemisphere, and the left ear projects exclusively to the right. Therefore, if it can be shown with simultaneous presentation of verbal commands that these cerebrum-separated patients can carry out instructions arriving in the left ear but report only those from the right, it can be inferred that the right hemisphere not only understands the commands but is capable of controlling the motor output, independent and unknown to the language-dominant, left hemisphere.

Experiment I: Dichotic Verbal Commands

Several commands were constructed and recorded in pairs on the left and right channels of a stereo recording tape. The commands were recorded so that natural stresses in the sentences would coincide, word for word, during the dichotic presentation. Unstressed words (e.g. "a," "the," etc.) in one ear would not necessarily be paired with unstressed words in the other ear. Each stimulus command was recorded by a female voice at a normal speaking rate such that the stresses were separated about one-half second apart.

Most of the commands required actions to be performed on simple pieces of apparatus such as a small knob, a bar, a disk, etc. Examples of the commands that were to be performed are "Turn the knob," "Slide the bar," and "Pull out the metal knob." The pieces of apparatus were constructed from wood, plastic, or metal and mounted on a response panel located in front of the subject. Vision was excluded during testing, so that each response to the command pairs was performed by reaching out and blindly selecting the correct object on the display panel, and then performing the required action. Each piece of apparatus was capable of being manipulated in several different ways (e.g. by pushing, pulling, turning, etc.) so that no associations could be made between the specific actions and the individual response objects. Familiarization of the apparatus was accomplished in a pre-test for that purpose which was performed both in free vision and blindly.

A typical trial commenced with a warning word, "Ready," presented binaurally. Approximately one second later, the two dichotic commands were heard simultaneously, one in each ear. The subject was allowed as much time as he needed to search for the appropriate pieces of apparatus and perform the required actions. When he had finished, or when he seemed unreasonably confused, the trial was terminated. As a rule, the subject was then required to verbally relate which two commands he had heard. The subjects were arbitrarily scored for correctness of the action and ability to repeat the commands. In instances where the correct action was performed on the wrong piece of apparatus or vice-versa, a premium was given for the correct action. A point system was used to rate the responses, only in order to give a general basis for comparison. A video tape was used to aid in analysis.

Observations indicated that the right hemisphere has a capacity for understanding and carrying out verbal commands. The best evidence of this is in cases where the left hand performed the commands that had been heard in the left ear while, at the same time, the verbal report was only of the command from the right ear. This indicated that the left hemisphere was either not aware of the left ear stimulus or had forgotten it. Presumably, it was the right hemisphere that had understood the command subsequently carried out the action by manual performance.

The best example was found in one of the adult subjects(R.Y.). He was permitted to use either or both hands with the instructions to perform the commands he heard in each ear. In the left ear, he had heard "Wave your hand in the air" and in the right ear he had heard "Scratch the top of the table." Immediately after hearing the stimulus, his left hand jumped in the air and the right started to scratch the table top. He verbally reported only the right ear command. It should be noted, however, that most responses from this subject were to the right ear commands and performed by the right hand.

Another interesting example of a case where the command from the left ear was performed and not verbally reported was seen in one of the younger patients (L.B.). In this series the subject was again allowed to use either his right or his left hand to perform the commands he heard in each ear. The right ear command was "Say your first and last name" and the command from the left ear was "Point a finger to the ceiling." The subject's first response after hearing the pair of stimuli was to hold out his right hand and say "Stop it!", meaning the tape recorder. The reason for this was that the recorder had been inadvertently left running after the previous trial and the subject took it upon himself to remind the examiner to turn it off this time. After his warning, the subject proceeded to raise his right arm and point straight up in the air with his index finger (i.e., the left ear command). At the same time he stated his full name (i.e. the right ear command). He then correctly reported what he heard in his right ear ("Say your first and last name") and after thinking a moment longer, he pointed with his raised finger to the left ear and stated that he had not heard what had been said in that ear.

Clearly, the left hemisphere was able to report and carry out the right ear command but was either verbally unaware or had entirely forgotten the command in the left ear. Meanwhile, the left ear command had been correctly performed, albeit with his right hand. Trials were generally not as clear as this. The key in this second case may have been the subject's preoccupation with properly turning off the tape recorder at the proper time. If his concern occupied the verbal thought processes of the left hemisphere, then it is conceivable that the verbal circuits were overloaded to the point where the information from the ipsilateral left ear was ignored. The right hemisphere, on the other hand, was free to attend to the left ear stimulus and consequently perform the appropriate action unimpeded and unnoticed by the left hemisphere. The only confusing aspect is the use of the right hand rather than the left to perform the left ear command. It is possible, however, for the motor system to gain control over the ipsilateral limbs, particularly in the younger cerebrum-sectioned patients(40,41). Of course, one cannot completely rule out the alternative possibility where performance of the left ear command was accomplished by the left hemisphere. If this should be the case, then it must further be hypothesized that the same verbal command that had initiated the manual response from the left hemisphere was immediately forgotten or was unretrievable by the speech apparatus.

Examples such as those just described occurred only a small number of times compared to responses where the right ear command was performed and reported, or that both the left and the right ear command were performed as well as reported. Better performance of the left ear commands is consistently observed in the cerebrum-separated patients when only the left hand is allowed to perform the commands and the right hand is occupied with some other "irrelevant" task. Examples of "irrelevant" tasks are palpating objects or putting pegs in a pegboard. In these cases the plan was to overload the left hemisphere in an effort to free the right for performance. Results showed the number of commands performed from the left ear increased while the number of times there were verbal reports from that ear were decreased. In several of these instances when commands from both ears were performed, the one from the left ear was usually performed first. In contrast, verbal report came first from the right ear, and then from the left. Many times verbal report came only from the right ear, but it never came only from the left.

The observation that more commands were performed from the left ear when the left hemisphere was kept occupied with an irrelevant task supports the idea that the right hemisphere can carry out verbal commands. However, it is still the case in most situations that the left hemisphere dominates in carrying out verbal commands from either ear. The hypothesis of right hemisphere comprehension of verbs is supported only by qualitative, and not quantitative, evidence. But the fact that in some instances the commands are performed from the left ear and not reported clearly demonstrates the dissociation between the hemispheres. The case was never observed where the right ear command was performed and the verbal report came from the left ear. More information is needed from these cerebrum-separated patients to judge the interaction between the ear pathways, disconnected left and right hemispheres, and the motor responses.

Experiment II: The Effect of Shadowing on Monaural Commands to the Left Ear.

A test was specifically designed to observe the execution of commands presented to the left ear while the subject was busily engaged in a difficult verbal activity, which presumably will occupy the left hemisphere more than the manual task of the previous experiment. The activity involved presentation of a list of common words to the right ear in such a way that the subject would have to repeat (shadow) each word aloud. At the same time, commands would be delivered to the left ear. These were made up of single action words (e.g. pull, turn, spin,etc.) that could be carried out on one simple piece of apparatus (a small knob). There was about one action word to every 5-10 shadow words and it was expected that the subject would continue repeating words throughout the entire test session. For baseline comparison each of the command words was presented in one trial run before the accompanying shadowing task.

The results show a more frequent performance of commands with the left hand during verbal activity. The effect appears as a shift towards greater use of the left hand which is reversed when verbal activity is discontinued. This was particularly striking in a cerebrum-separated patient who had undergone a right temporal lobectomy. The left hand was used almost twice as often during the shadowing than during the control task. The interpretation of these observations is that the left hemisphere is occupied with on-going verbal activity so that the right hemisphere is more likely to be free to carry out commands.

However, there were also many times when these same subjects performed the whole test with their right hand while the left remained idle. In other words, not only was there no shift to the left hand during verbal activity, but the left hand failed to perform any of the commands--the right hand performed them all. When the test was changed so that subjects were required to use the left hand alone, they performed no better than when they were required to use only the right hand. If the right hemisphere were controlling the left hand, one would expect the commands arriving in the left ear to have a special advantage for the left hand in most trials. Since they did not, it is presumed that the left hemisphere was doing all the work in these cases. This was supported by evidence in the reverse case where the command words arriving in the right ear with shadow words in the left, resulted in an improvement by both hands. Therefore, it is concluded that the left hemisphere maintained control in spite of its occupation by verbal activity; expression of the right hemisphere could not be determined. Evidence exists in this test to indicate that verbs can be comprehended and expressed manually by the right hemisphere. However, overwhelming data also point to the considerable dominance by the left hemisphere even when it is kept occupied by verbal activity.

Experiment III: The Effect of Verbal Memory on Monaural Commands to the Left Ear.

The experiment just described was a dichotic test in the sense that separate stimuli were played to each ear. However, no attempt was made to pair the command with the shadow words. Consequently, the two stimuli did not necessarily sound at the same time. Therefore, another test was constructed in which simultaneous left-right presentation was instituted. The verbal activity intended for occupying the left hemisphere was changed from a shadowing task to a memory test. In the right ear, the subject heard a list of four common words in succession. In the left ear a single command word was presented so that it was heard at the same time as the third word of the list. The task was to perform the action designated by the command and then recite the four right ear words.

The results were unexpected. When the subject was allowed to perform the action with either the left or the right hand, only the right actually responded. When responses were restricted to performance by the left hand alone, the commands could be carried out but at a level inferior to that of the right hand. Presentation of the commands to the right ear, instead of the left, improved the results for each hand although the right still maintained a clear superiority. These observations provide strong evidence that neither the verbal memory task nor the dichotic presentation of the command word was sufficient to block left hemisphere control. What is even more surprising is that verbal recall of the four words in the right ear was greatly affected. This finding is contrary to the normal result for dichotically-presented commands where the right ear was nearly always reported correctly(27,42). In this test, the subjects could typically recall the first or second word of the list but would fail on the third and often the fourth. Considering only the third word since it was the one that had been paired with the command word from the left ear, it is seen that more than half of the errors were total omissions; the subject claimed he did not hear the words at all. In the remaining cases, the subjects substituted the command words from the left ear as if they had belonged to the list. In many of these cases, the subjects acted as if there was no stimulus command in the left ear at all and accordingly performed no response action.

These observations seem contradictory to the general belief in previous dichotic studies where it was supposed that ipsilateral pathways to the left hemisphere are strongly dominated by contralateral routes. On the contrary, it is seen in the present experiment that the left hemisphere is in fact capable of separately attending to either of the two pathways, and that information in the ipsilateral pathway appears to suppress the information in the contralateral ear in about 20% of these cases.

Summary and Conclusions

Three conclusions may be drawn from these experiments. First, the right hemisphere can comprehend and perform spoken commands which are dependent upon the understanding of verbs and the performance of actions. Previous studies have hinted at the comprehension of spoken commands but direct evidence was lacking. For example in the past, auditory commands were presented so that both hemispheres could hear, and as the left hand reached out to perform the task, the left hemisphere could well have guided it along. In the present study, commands that involved manual actions could be carried out by the left hand without verbal awareness of the left hemisphere. It was concluded that this was a result of right hemisphere comprehension. This left-right field separation has already been found for the visual, tactual, and olfactory modalities and now can be obtained under certain conditions for the auditory modality.

A second observation is that in spite of the right hemisphere's capability, the left hemisphere is strongly dominant during most of the verbal task performances. More of the right ear commands were carried out and the right hand was used more often. Even when the left hand was forced to be used alone, it was the right ear command that was most often performed, whereas the left ear command was either ignored or performed along with the right. The interesting cases which lead to the conclusion of comprehension of the right hemisphere are the few where the left hemisphere was verbally unaware of the left ear commands that were being performed. In the other cases left hemisphere dominance is not unexpected since verbal comprehension is what the left hemisphere does best. This conclusion supports findings of Levy et al.(40) where they indicate that the hemisphere which is dominant for a particular task will normally seize control of the ipsilateral as well as the contralateral motor system.

The final observation is that the left hemisphere can apparently monitor the ipsilateral auditory pathway from the left ear. This was hinted by consistent performances by the right hand of the commands from the left ear. The actual suppression of the right ear by the left ear stimuli in dichotic listening task of Experiment III confirmed the observation to be valid. This finding is contrary to the general belief that the ipsilateral pathway is completely suppressed by the contralateral in tests with competitive stimuli in each ear. Apparently the left hemisphere (and presumably the right) can separately attend to either the ipsilateral or the contralateral auditory pathways depending, perhaps, on the meaningfulness of the stimulus. This suggests separate mechanisms exist within each hemisphere for analyzing information from each pathway. Further study of this problem is described in the next Section.

IV. COMPARISON OF IPSILATERAL AND CONTRALATERAL AUDITORY PATHWAYS IN CALLOSUM-SECTIONED PATIENTS BY USE OF A RESPONSE TIME TECHNIQUE.

Introduction

Left-right ear asymmetries arising from dichotic listening experiments are ultimately explained by perceptual differences in cerebral processing. However, these differences depend, in the first place, upon evidence which demonstrates that the contralateral auditory pathways have stronger cortical representations. Part of this evidence is derived from electrophysiological work in animals where greater amplitudes were recorded for evoked potentials in the auditory cortex contralateral rather than ipsilateral to the stimulated ear(1,2,3). Additional support for contralateral superiority is provided by human patients with unilateral temporal lobe lesions where a greater degree of hearing deficit is measured in the ear contralateral to the damaged hemisphere(4,5). It is predicted, therefore, that information reaching the cortex from the contralateral ear has greater functional potential in the brain than information from the ipsilateral ear. Consequently, the first step toward explaining asymmetry in dichotic listening experiments is to eliminate ipsilateral pathways from consideration based on their relative insignificance. This leaves the two contralateral pathways transmitting primary auditory information from each ear to the opposite cerebral cortex. If one hemisphere is specialized for certain types of stimuli, one would predict that a superior score for the contralateral ear will reflect this superiority. Accordingly, right ear dominance has been shown for verbal material such as words, letters, and digits(6,7,8), whereas melodies, chords, and other non-verbal sounds have been favored by the left(9,10,11).

It is of interest to reconsider the functional capabilities of the so-called "weak" ipsilateral pathway. Patients with complete surgical division of the corpus callosum have demonstrated a dramatic suppression of the left ear when asked to recall words presented to both ears simultaneously(12,13). Presumably, without the callosal contribution, the pathway from the left ear to the ipsilateral (speech) hemisphere becomes behaviorly non-functional under conditions of dichotic listening. In contrast, virtually every word presented in the left ear alone, without right ear stimulation, was recalled easily and without hesitation. The conclusion is that the ipsilateral pathway possesses the same facility to transmit verbal information as does the contralateral pathway, but that it is inhibited or suppressed when both ears are presented with similar but different stimuli at the same time.

Conclusions from the last Section indicate that even this idea bears examination. While it is true that under most conditions the contralateral pathway inhibits the ipsilateral, indications were that certain factors of attention may cause the ipsilateral pathway to inhibit the contralateral. The indication is that these are separate, and in some sense, independent systems functioning in each hemisphere.

It is not clear how these systems might be organized and what, if any, are their differences. The present study provides data on this problem by comparing differences in response time to stimuli presented in each of the ears. A model is presented which chases the auditory engram through the cortex and outlines cognitive processes that account for the different response times obtained for various tasks.

Method

Subjects

The main group of subjects were 6 epileptic patients who had each undergone complete surgical division of the corpus callosum and anterior commissure in one operation by P.J. Vogel. Three of the patients were young adults under 20 and three were middle-aged in their 40's. Typical commissurotomy symptoms observed on these patients have been reported previously(14,15,16,17).

The control population consisted of two groups of subjects. The first were two patients with complete surgical transection of the anterior commissure and partial division of the corpus callosum sparing only the splenium. Both patients were in their late twenties and were operated more recently than any of the patients with complete section, but not with two years of testing. These patients are characterized by their remarkable lack of commissurotomy symptoms(18), but with some exceptions in motor control(19).

The second control group includes 7 unoperated subjects. Five are healthy, right-handed individuals; the other two are medication-controlled epileptics seen through the courtesy of Dr. J.E. Bogen.

Procedure

General: The test battery consisted of lists of words which were pre-recorded on one channel of an audio recording tape. For testing, the words were played to each subject through a set of stereo headphones which were connected through a silent switch so that the examiner could direct each of the stimuli to either the left or right ear. The subject was told that speed of response was the most important part of the test, and that he was to react as quickly as possible as soon as he heard each word. The response mode was either vocal or manual, differing from test set to test set as described below. A digital interval timer located in front of the subject displayed each response time in milliseconds and provided continuous reinforcement in an effort to induce high motivation.

The entire test battery was presented twice to each subject--once with the stereo headphones worn in the normal position and once with them reversed. Therefore, systematic errors that might favor one ear over the other could be excluded. The length of one test session varied according to the fatigue of each subject but never exceeded 1½ hours. The subjects returned as many days as necessary to complete the entire test battery.

Each subject's response was recorded on the second channel of the recording tape. The reaction times could be determined by playing back the tape and measuring the time between the stimulus and the response with the interval timer. The data was automatically printed on a paper tape for a permanent record.

Tests and Specific Procedures: The test sets for this experiment were divided into two groups each of which were made up of several lists of words. Group I was a reaction time test in which each word was to be repeated (shadowed) immediately upon presentation. Group II was a vigilance task which required an immediate response only when a key word was heard.

Group I, Set I: The stimuli in this set were 18 common one-syllable words arranged in an arbitrary order. The initial phoneme of each word was voiced or unvoiced consonant stops (p,b,d,t,k,g) so that the uttered onset of a word would be sudden. A total of 36 words, constructed from two successive presentations of the same 18-word list, comprised the test set. The 36 words were presented one at a time to the left or to the right ear on a pre-determined pseudo-random sequence, but with the constraint that no ear was stimulated more than three times in a row. The subject's task was to repeat (shadow) each word as quickly as he was able. The left-right presentation schedule was arranged such that a word directed to one ear in the first half of the test would be directed to the other ear in the second half. This method insured that each of the 18 words would be presented once to each ear, so that a reaction time comparison of left-right differences could be made for each word in the same test presentation. The words of the list were separated by silent intervals that varied in length in a 1-2 second range so that the subjects could not anticipate the arrival of each new word.

Set I-B: The same words used in Set I were repeated but with a different left-right ear presentation schedule. Instead of a pseudo-random sequence, the first 9 words of the list were presented as a block to one ear, then the next 18 words were presented to the other ear, and finally, the last 9 were presented to the original ear. This scheme prevented a constant changing of attention from ear to ear but at the same time preserved the arrangement where a word presented to one ear in the first part of the test was presented to the other ear in the second part.

Set II: A copy of the word list used in Set I including the same silent intervals and the same pseudo-random left-right presentation comprised the stimuli of Set II. However, the method of response was changed so that the subject was no longer required to repeat each word but rather signify its arrival by immediately saying, "Now." The purpose of this set was to obtain a verbal response time where word discrimination or comprehension was not necessary.

Set II-B: The stimuli of Set II were repeated but presented in the block form as described in Set I-B.

Set III: The methodology of this set is the same as Set I except that a different list of 18 words was used to comprise the total list of 36. The same pseudo-random presentation schedule was used. The main difference was that the silent intervals between words were reduced to a ½-1 second range in order to encourage faster response times. It was possible at these new presentation rates for a slow response by the subject to coincide with the onset of the next word in the list which is an effective "negative" reinforcement prodding the subject to respond faster.

Set III-B: This test is the same as Set III in the block form.

Set IV: Set IV has the same methodology as Set II where the subject's response was the word, "Now." The word list and rate of presentation was copied from Set III.

Set IV-B: This test is the same as Set IV in block form.

Group II, Part I (Vocal), Set V: A list of 36 words was constructed from 18 common one-syllable words plus 18 repetitions of the word, "talk." Each of the 18 talk's was interspersed among the other 18 words in a pseudo-random order with the constraint that there were no more than three repetitions in succession. The silent intervals between each of the words was ½-1 second, similar to Set III. The subject was requested to listen to each word of the list and as soon as he heard the word, "talk," he was to repeat it. For the other words, he was to remain silent. The words of the list were directed to the left or right ear on a pre-determined pseudo-random schedule; the block versions were not used.

Set VI: A copy of the list of words in Set V was used for the stimuli. The subject was again instructed to listen to each word of the list responding only to the word, "talk." However, in this test he was to say, "now," instead of the word, "talk."

Part II (Manual), Set V-M: Set V was repeated but instead of a vocal response, the subject was asked to push a button with the index finger on his right hand whenever he heard the word, "talk."

Set VI-M: Set VI was repeated and the push-button response was to be performed by the index finger of the left hand.

Results

The first question to be answered is whether response times to words presented to one ear are faster than response times to words presented to the other. Secondly, it is of interest to obtain some idea of the absolute differences in response times for each of the tasks. The first question is examined as follows:

Sets I-IV:

In the test list for each set, every stimulus word was presented twice in one trial run--once to the right ear and once to the left. Therefore, it was convenient to pair the response times such that the left ear presentation was compared to the right ear presentation of the same word in the same trial run. When the right ear was faster, the score for the pair was "plus" and when the left ear was faster, the score was "minus." Under the null hypothesis where no ear is better than the other, an equal number of pluses and minuses would be expected. That is, in a normal distribution of response times, either ear has a 50% chance of being faster for any one trial. (An analogy can be drawn to flipping an unbiased coin where there is a 50% chance of obtaining heads on each flip.) Consequently, we can compare the score distributions for the ear performances in each test to fit the binomial distribution: $P = \sum_{n}^{N} \frac{N!}{n!(N-n)!} p^{N-n}q^{n}$; where P is the probability of obtaining the score of n or more and N = total number of comparisons, n = number of times the right(left) ear is faster and $p = q = \frac{1}{2}$. In the present tests, the probability that is obtained must be multiplied by 2 in order to account for the possibility that the right(left) ear is faster <u>or</u> slower than the left (right).

The results are striking. For every subject whose forebrain commissure had been surgically divided, the right ear was faster in every word repetition test(i.e. Sets I, I-B, III, III-B). In half of these instances, the predominance of the right ear's speed was significant at the 5% level; in the other half of the instances, but one, the trend was in favor of the right ear. When the scores for each of the subjects were summed, the totals were significant($p < .01$) indicating the right ear was faster than the left a significant number of times.

In contrast, these same subjects showed no significant superiority for the speed of one ear over the other in the simple response test sets where the task was to say the word, "now," for each word stimulus(i.e. Sets II, II-B, IV, and IV-B). In half of these cases, the subjects were only slightly faster with their right ear while in the other half, they were slightly faster with their left. At no time was there any significant difference between the ears. In one of the sets (Set II-B) the right ear was slightly faster than the left ear for each of the subjects. Consequently, the total score for that set reached the 5% level of significance.

It is of interest to compare test sets in which the same words were presented under the same stimulus conditions, but the responses were different (e.g. Set I--word repetition vs. Set II--"now"). These comparisons are depicted in Figures IV-1 - IV-4. The histograms represent the difference between the number of times the right ear was faster (= R) and the number of times the left ear was faster (= L). The differences were plotted as percentages of the total number of comparisons. That is, R-L/R+L x 100. With this graphing method, a score of +100 would be obtained if the right ear were always faster, and -100 would be obtained if the left ear were faster. Zero indicates the right and left ear were faster equally

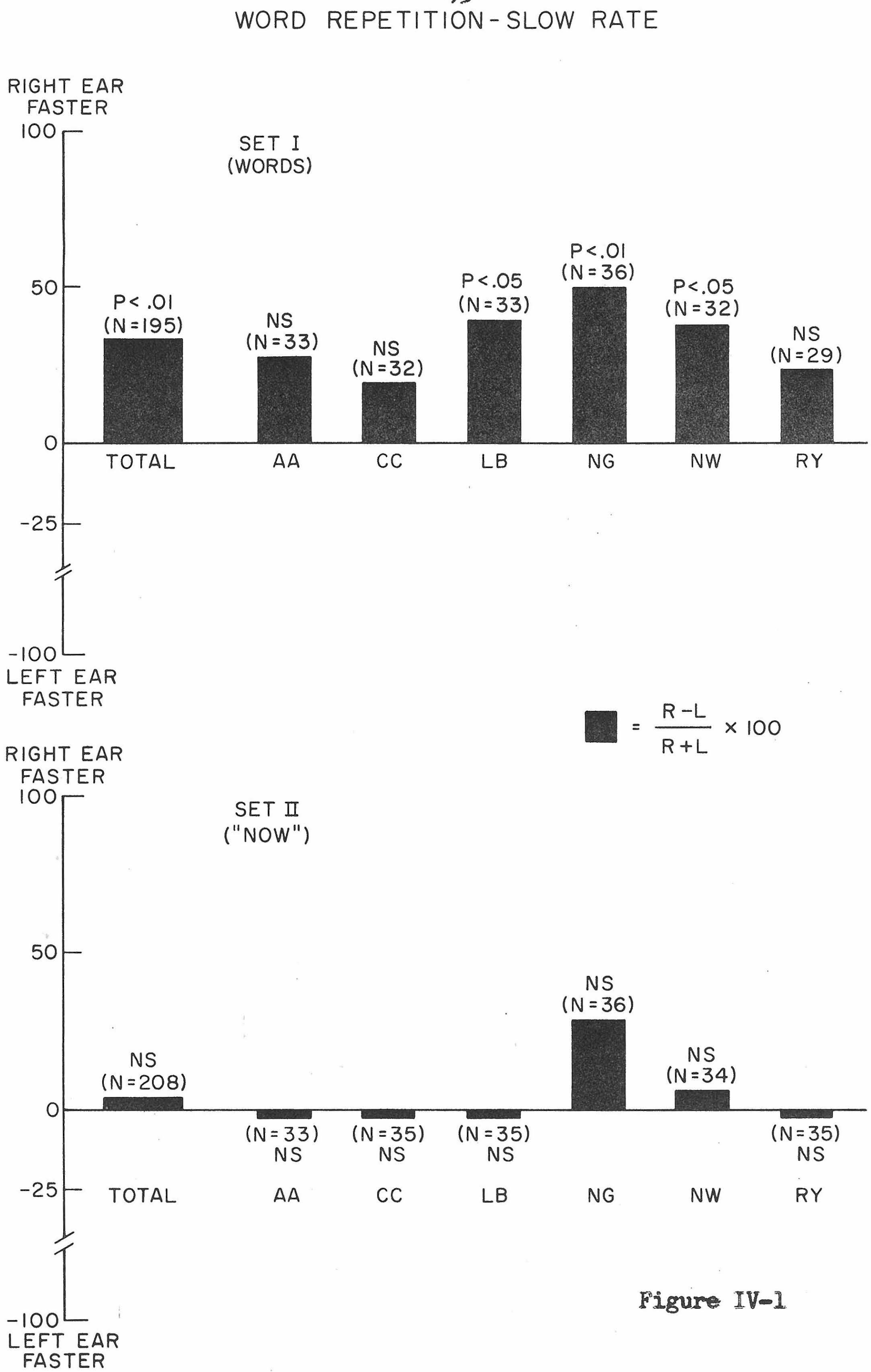
WORD REPETITION-SLOW RATE
RIGHT EAR FASTER
100
50
0
-25
-100
LEFT EAR FASTER
SET I (WORDS)
P<.01 (N=195)
NS (N=33)
NS (N=32)
P<.05 (N=33)
P<.01 (N=36)
P<.05 (N=32)
NS (N=29)
TOTAL
AA
CC
LB
NG
NW
RY
= (R-L)/(R+L) × 100
SET II ("NOW")
NS (N=208)
(N=33) NS
(N=35) NS
(N=35) NS
NS (N=36)
NS (N=34)
(N=35) NS

Figure IV-1

WORD REPETITION-SLOW RATE (BLOCK FORM)

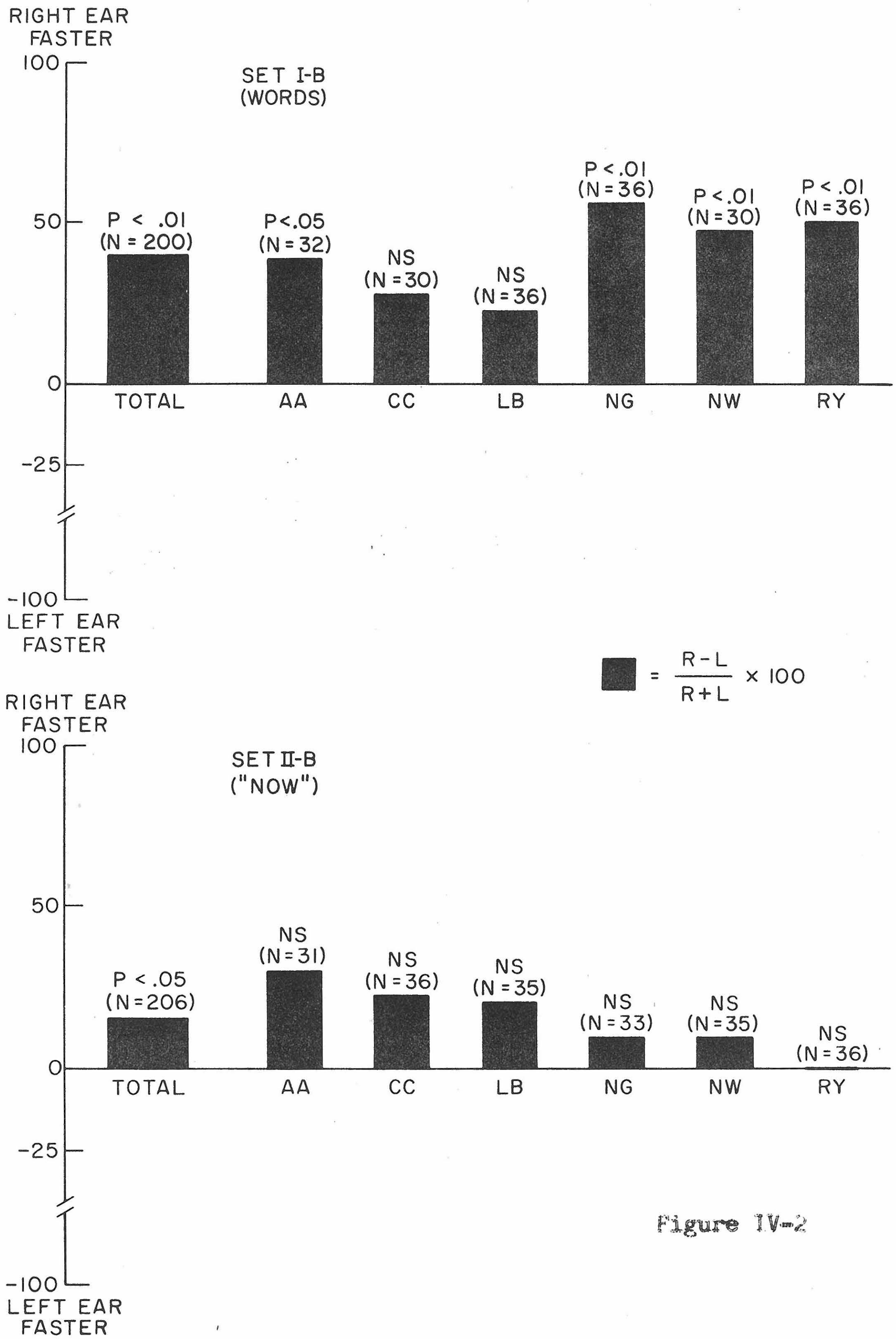

Figure IV-2

WORD REPETITION - FAST RATE

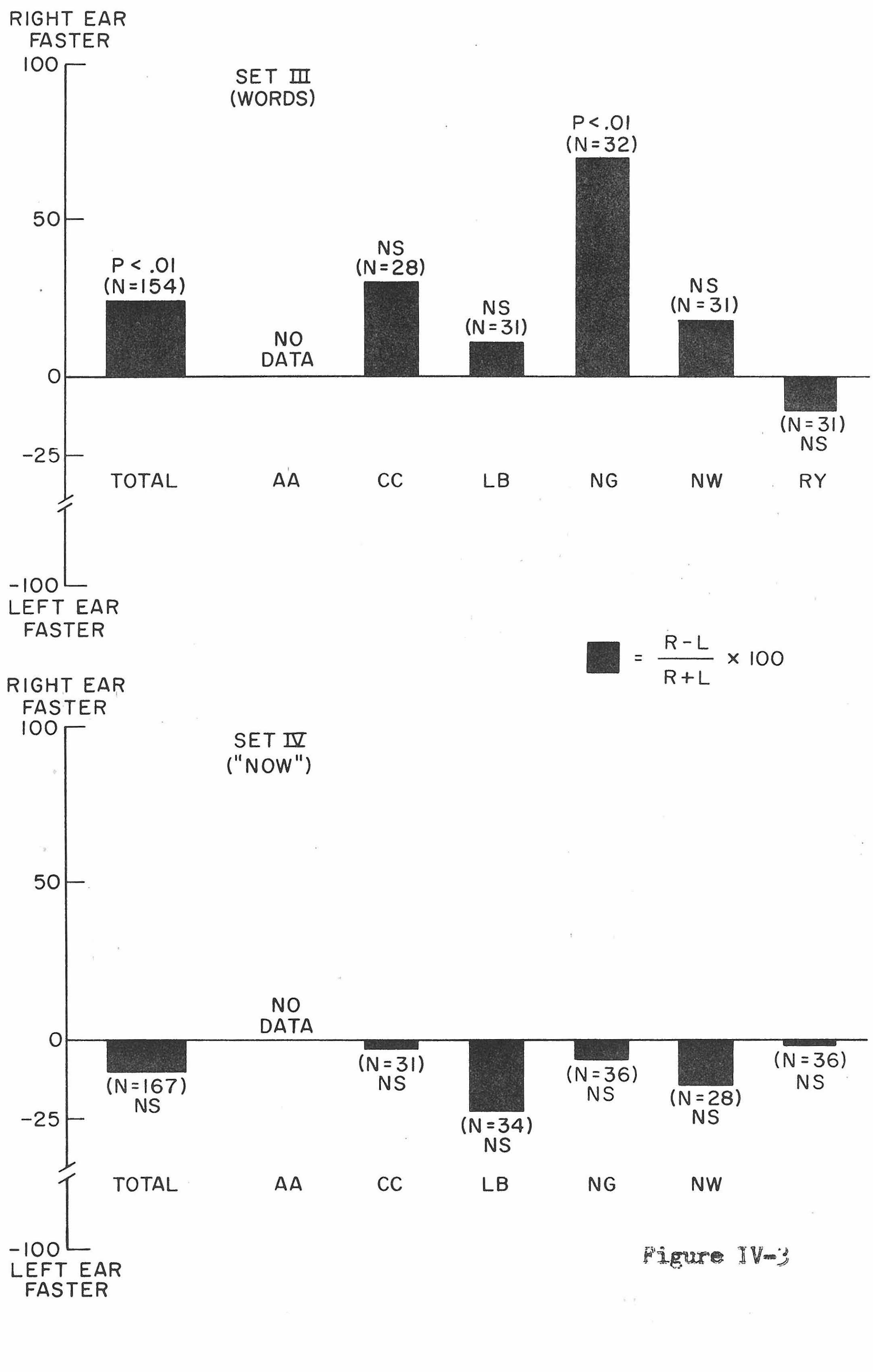

Figure IV-3

WORD REPETITION - FAST RATE
(BLOCK FORM)

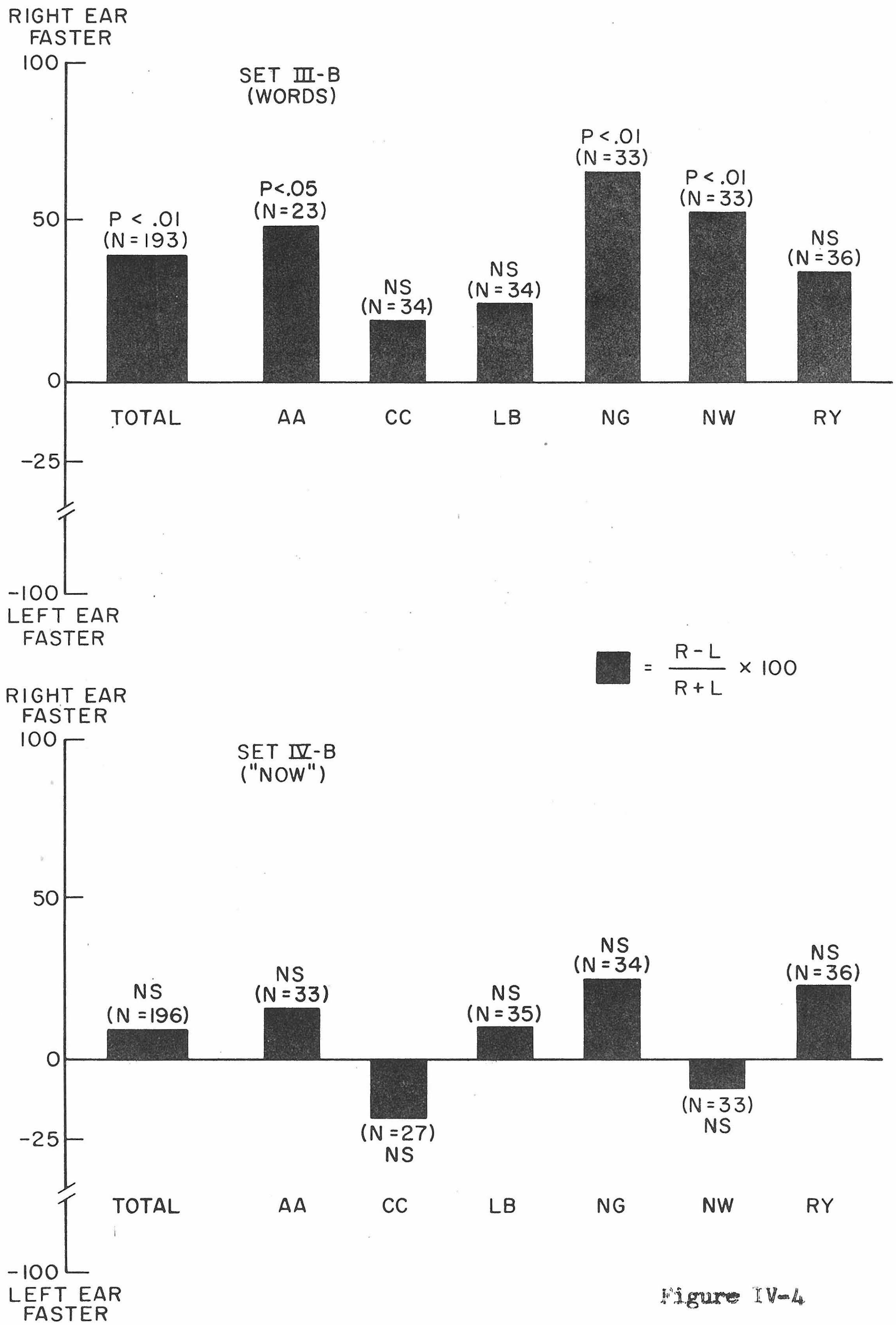

Figure IV-4

often.

The striking observation is that the right ear of each subject had a high percentage of faster response times in the word repetition tasks. If the numbers for all of the subjects are summed the totals for each set are highly significant($p < .01$) for a faster right ear. At the same time, there is a mixed array of weak trends in favor either of the left or of the right ear for the simple response tasks. The total difference for each of these sets is near zero, except one in which the right ear just reaches the 5% level of significance. It can be seen, incidentally, that the right ear percentages are higher subject for subject, test for test in the block version of the test sets as compared to the regular versions. The difference is that for the block version the words are presented as groups first to one ear and then to the other; for the regular version, the words are presented alternately in a non-predictable sequence back and forth between the two ears. The reason for the two versions of the tests was for a mutual control. The block version controlled for problems that might be incurred in attentional switching from ear to ear; the pseudo-random presentation controlled for possible attentional biases. The results for the two test types were essentially similar except for the right ear bias as noted for the block version.

Another observation is that there is a correlation between a subject's score on the word repetition test and the simple response test. Subjects who were fast with the right ear many more times than with the left in the word repetition tasks, tended also to be fast more times in the simple response tests. Those who had less of a right ear predominance in the word repetition task tended to have negative (left ear faster) or near zero scores in the simple response task.

The results for each test for all the subjects were summarized in a similar analysis but with more stringent statistical conditions. The protocol of presentation had been such that each word in a set was not only presented twice in a single trial run, but also repeated twice again in a second trial run in which the stereo headphones were reversed. Therefore response times for any word could be paired twice, once for the first trial run and once for the second. With this scheme, a "plus" was scored only if the right ear was faster in both of the trial runs. A "minus" was scored if the left ear was faster in both sessions. All other combinations are statistically "uninteresting" and were ignored.

Again one would expect to find an equal number of pluses and minuses under the null hypothesis. The scores were compared with the binomial distribution as before; the results are depicted in Figure IV-5. It is seen that the right ear maintains its superiority since it is significantly faster more often than the left in the word repetition tasks. The other (simple response) test sets showed mixed results, none of which were significantly in favor of one ear or the other. It is also observed that the block versions of the test had a stronger bias for the right ear; those tests with the faster presentation rates (Sets III, III-B, IV, IV-B) were biased in a direction away from the faster right ear.

RESPONSE TIME
(SUMMARY)

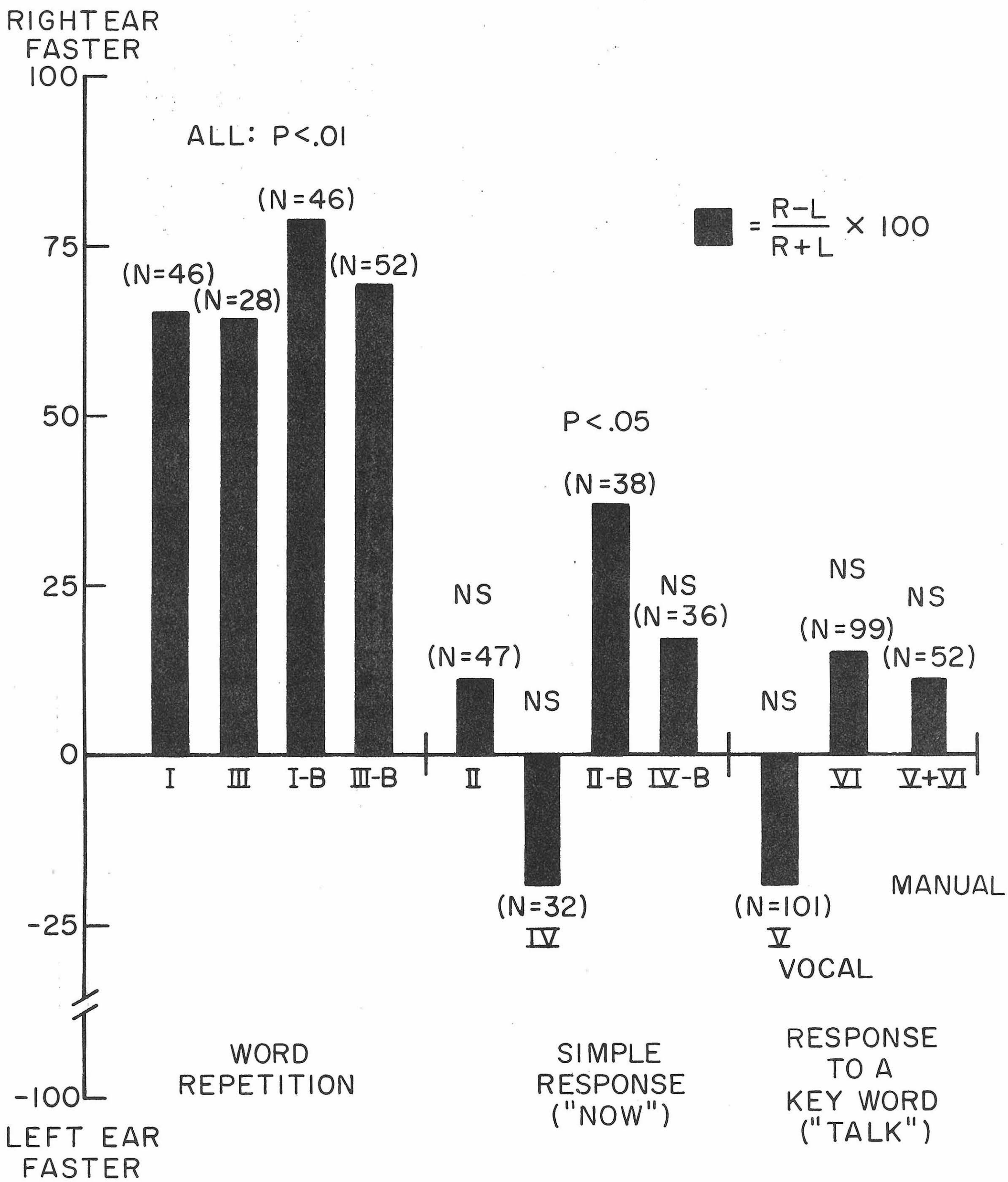

Figure IV-[illegible]

The right ear superiority for the patients with complete surgical division of the commissures for the word repetition stands in contrast to no significant differences on the simple response tests. Among the control groups, the two medicine-controlled epileptics seemed to have faster left ears more often for most of the tests while the other two groups had no apparent biases. None of the biases for the epileptic group were significant. See Figure IV-6.

Sets V and VI:

The results for these sets were analyzed in a way similar to that described for Sets I-IV. Each set was presented twice: once with the earphones in one direction and once with them reversed. Therefore, a word that had been presented to the left ear in the first presentation was presented to the right in the second and vice-versa. Consequently, left-right pairs could be made as in previous analyses. A "plus" was scored every time the right ear was faster, and a minus every time the left ear was faster. The results were compared in the binomial distribution.

Neither patients with complete division of the forebrain commissures nor any of the control groups were faster a significant number of times with either ear. The trends for every group, experimental and control alike were in favor of a faster left ear for the task in which the subjects were to repeat only a key word ("talk"). The results were mixed for the other versions of this task where the response was to say, "how," or the response was manual rather than vocal. See Figure IV-7, and IV-8.

WORD REPETITION
(CONTROLS)

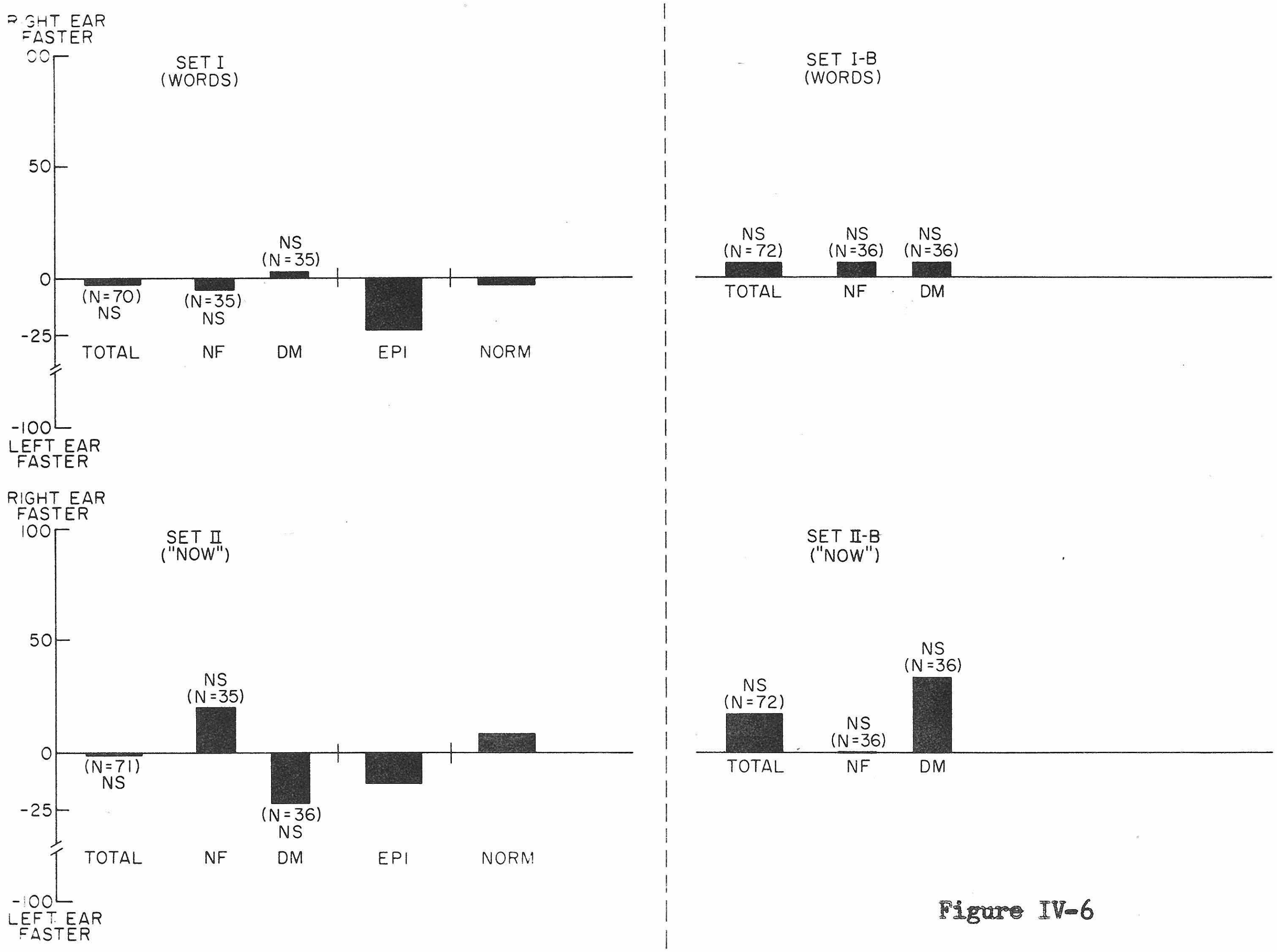

Figure IV-6

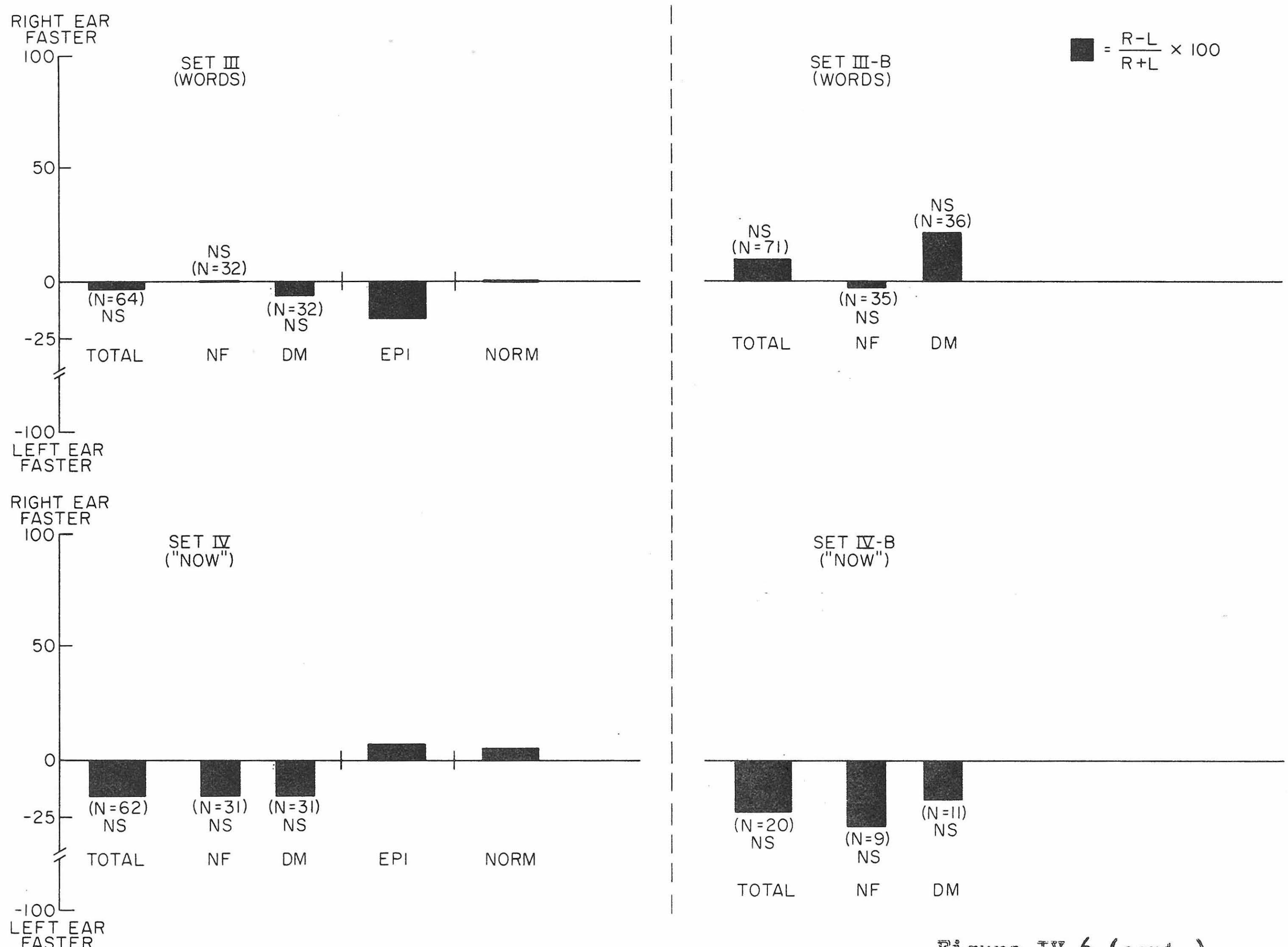

Figure IV-6 (cont.)

RESPONSE TO KEY WORD

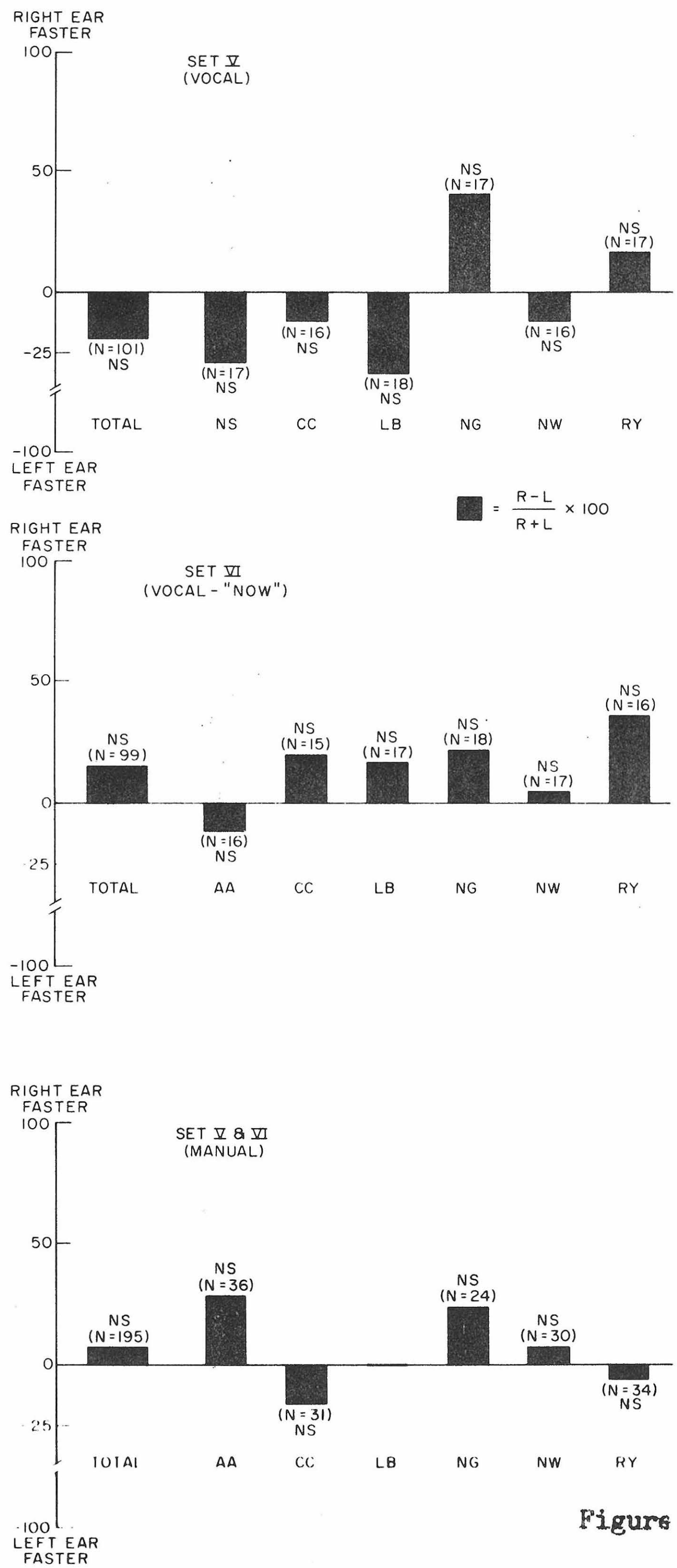

Figure IV-7

RESPONSE TO KEY WORD
(CONTROLS)

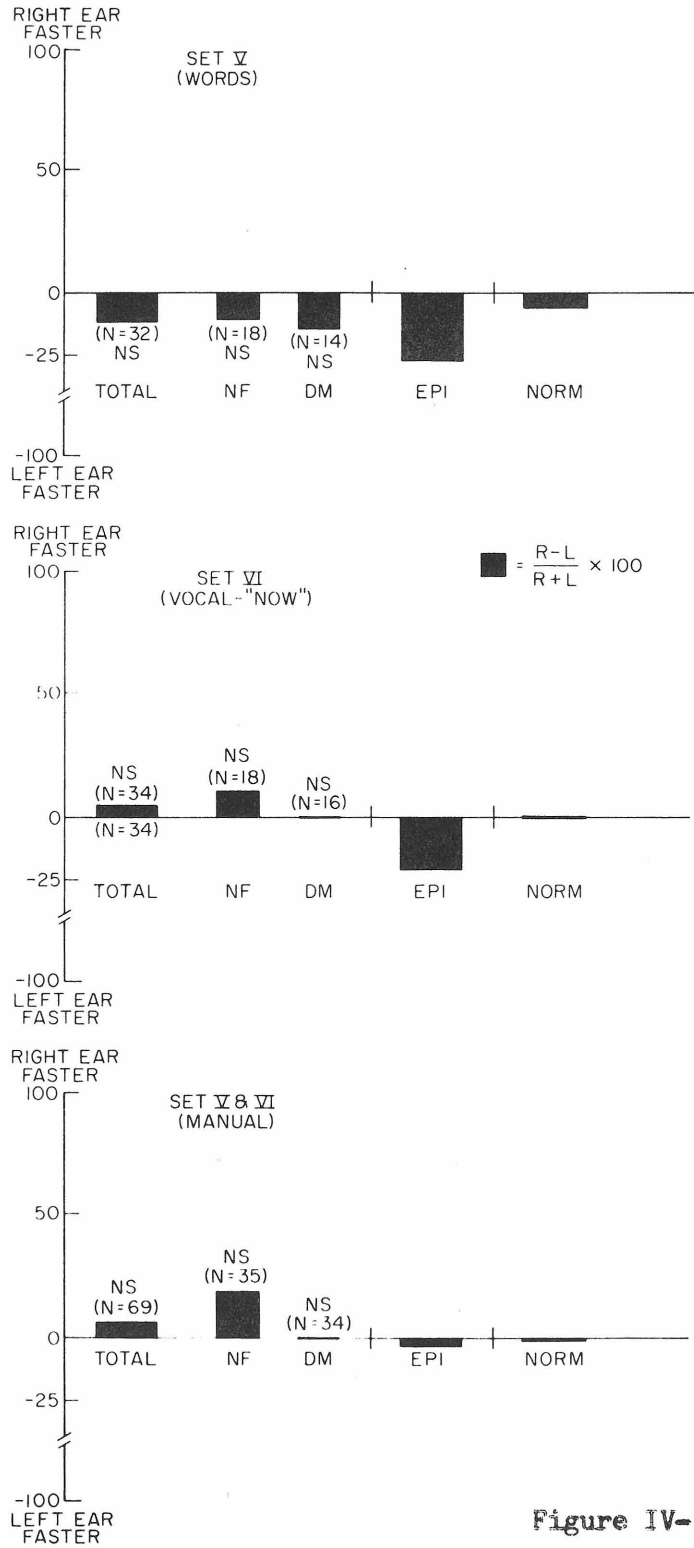

Figure IV-8

In summary, we have shown that the right ear of the patients with complete surgical division of the forebrain commissures is significantly faster more often for repeating words and not for any of the other tasks. The normals showed no significantly faster ear for any of the sets including the word repetition task. We are now faced with the task of assessing the magnitude of the differences between the ears in terms of absolute differences in response time.

The major problem in such an undertaking is the high degree of variability. Subjects tend to get "goofed up" from time to time and as a result their response times are greatly lengthened. It was reasoned that if ear differences were to have any physiological meaning at all, only the fastest response times would be the most help. The slower times would likely be influenced by other factors such as trial-to-trial confusion, swallowing, breath control, etc. For most subjects, casual observation indicated less than 10% of the response times were "aberrantly" longer than the rest and so it was decided, at the risk of throwing out some "good" data, that 15% of all response times for any one test set would be omitted, indiscriminant of the ear from which the response was obtained. Differences would be calculated between the means of the remaining 85% of the response times for each subject. With this method, about twice as many numbers were eliminated from the left ear than from the right from the word repetition tasks and approximately equal numbers for all the rest. See Table IV-1 for a summary of mean differences between the ears for all cerebrum-sectioned subjects on all tests. The results must be viewed with caution because of the difficulty of defining a "response

TABLE IV-1

Mean Ear Differences for Response Times (L-R)

(in milliseconds)

	Word Repetition				Simple Response ("Now")				Key Word		
									Vocal		Manual
Ss	I	I-B	III	III-B	II	II-B	IV	IV-B	V	VI	V+VI
AA	14	54	--	28	3	31	--	1	21	-2	51
CC	4	22	28	2	9	18	6	5	20	5	27
LB	7	13	5	10	-7	4	-60	4	-45	24	7
NG	30	27	37	20	15	6	30	22	30	22	19
NW	26	23	2	14	8	6	-2	5	-9	14	9
RY	8	18	-1	18	-8	0	1	-4	11	-3	-8
Average	15	26	14	15	3	11	-5	6	5	10	18

time."

The overall differences in the means for the word repetition task is about 15 msec. in favor of the right ear for three of the four tests, and 26 msec. for the other. This would give an overall difference of about 18 msec. For the simple reaction time tests the total differences ranged from 5 msec. in favor of the left ear to 11 msec. in favor of the right. This averaged out to be about 4 msec. in favor of the right ear.

The right ear bias for word repetition is more prominent for the block presentations of this test where the advantage for the right ear is 5 msec. greater than when the word presentations were unpredictably switched between the ears. For the simple response test the right ear is favored by 8 msec. for the block form with no differences for the other.

When the mean differences were recalculated with a less stringent criterion for omitting data, the difference in favor of the right ear was about 30 msec. for the word repetition task and less than 5 msec. in favor of the left ear for the simple response. In these calculations only the response times that seemed unusually long compared to the others were omitted. Only about 5% of the response times were eliminated in this way.

There was a great deal more variability in the means for the sets in which there was a response to a key word (Sets V and VI). Therefore, one should view the mean differences here with extreme caution. It can be seen that for each of the tasks the superiority is about 11 msec. in favor of the right ear which is slightly smaller than the differences for the word repetition tasks. It should be remembered, however, that in the previous analyses for these tests, there were no significant differences between the ears. Controls were also variable in this task and showed approximately the same left-right differences in the means.

The mean difference in response times for controls in the word repetition tasks and in the simple response tests were in general less than ±5 msec. This is in accord with the lack of ear asymmetry for both types of tests that was demonstrated in the foregoing analysis.

Discussion

The patients with complete surgical division of the forebrain commissures were significantly faster in repeating words presented to their right ears. That is, words presented to the ear contralateral to the speech hemisphere could be repeated faster than words presented to the ear ipsilateral to the speech hemisphere. This result is in contrast to normal subjects who show no ear differences in word repetition. We can conclude that the cause of the ear differences is the loss of critical fibers in the corpus callosum and that the two auditory pathways from the ipsilateral and contralateral ear are not part of equivalent systems. The lack of ear differences in two patients with partial surgical division of the callosum is assurance that the phenomenon is not simply a result of operative procedures alone.

We must first decide whether the asymmetry of the response times is simply due to differences in the ipsilateral ear-to-cortex pathway as compared to the contralateral. The absence of ear differences on the simple response tasks is an indication that it is not.

In order for the cerebrum-separated subjects to have responded equally as fast to the word, "now," (i.e. the simple response), the words must have arrived at the cortex at about the same time from either of the two ears. Therefore, the ear asymmetries must be explained by some other delaying factors encountered by the ipsilateral route at the cortical level.

It is hypothesized that two separate systems exist: one for information arriving in the contralateral pathway and one for the ipsilateral. How these systems differ and where they merge for the final common pathway to the vocal apparatus is yet to be determined.

The first level in a cortical auditory system, once the presence of a stimulus has been recognized, is stimulus analysis--a recognition process. It is possible that ear differences of response time in the word repetition tasks are due to a less efficient analyzing or recognizing process for stimuli from the ipsilateral ear. This hypothesis has been examined by the test sets which require the subject to make a response to a key word (Sets V and VI). It will be remembered that the task in these sets was one in which the subject listens to a list of words but only responds when he hears a key word. If there is a perceptual asymmetry between the ears, a left-right difference in response time would also be expected.

The results showed no differences between the ears. Either ear could recognize the key word and make a response equally as well. Furthermore, there was no difference in the number of errors for either ear on this task nor on any other including the word repetition task, indicating essentially the same proficiency in perceiving the words. It is concluded, therefore, that the recognition processes of the two systems are equivalent at this stage.

Once a word has been recognized in the word repetition task, the proper pattern of motor impulses must be retrieved from a memory of that word. The impulses must be made available to the motor pathways which carry the message to the speech musculature. In all tasks but the word repetition task, the retrieval has been accomplished ahead of time--the subjects know which word they are going to say. This is not so in the word repetition task where the subjects do not know which word they are to say, and therefore must retrieve the motor pattern from memory. While it is true they must then transcribe the pattern into action, all of the tasks require the same process which would argue against ear asymmetries in this last stage.

It is proposed, therefore, that the differences in response time are a function of a memory search process. It is felt that the cortical system for the ipsilateral pathway is less efficient or slower in "remembering" or searching for the memory of the correct word pattern. The data from these studies do not provide a direct check for this hypothesis, but most of the other alternatives have been ruled out. The differences in the mean reaction times indicate that the two systems differ by a few synapses which is supportive of the idea that the contrasts between the systems are simple. The general consistency of the results for the cerebrum-separated patients is encouragement to seek further tests of the differences in the ipsilateral and contralateral auditory systems in each hemisphere.

SUMMARY AND CONCLUSIONS

In the first part of this Thesis, hemispheric asymmetries were studied in music-oriented right-handers by a dichotic listening technique. The results demonstrated that chords or, at least chord-like stimuli, are preferentially processed by the right (non-speech) hemisphere while rhythmical melodies were equally-well handled by either hemisphere. These findings suggest that the usual designation of "non-verbal" is an oversimplification of the right lateralized cognitive abilities.

A second study on patients with intracarotid amytal showed similar results. It was found that the right hemisphere had a greater contribution to pitch control for singing than did the left while either hemisphere could participate in the correct production of rhythms. This is further supported by observations on two young patients who had undergone complete hemispherectomy for non-infantile causes. One patient, with right hemispherectomy and no aphasia, sang poorly and was unable to distinguish pitches that differed by less than a musical step. In contrast, the other patient had a left hemispherectomy and could sing with excellent ability and pitch control, yet had severe anomia and agraphia with several disorders of expressive speech.

It was concluded from these data for the lateralization of chords and not melodies and for the observations of pitch control for singing and not for rhythm, that the distinctive feature that characterizes right hemisphere ability is "non-temporality." Chords are conspicuously non-temporal whereas melodies have both temporal and non-temporal qualities. Singing was deficient only in pitch control whenever the right hemisphere was not functioning. It was suggested that the quality of non-temporality reflects basic underlying processes that are involved in right hemisphere performance. On the contrary, others have indicated that the left hemisphere may be specifically organized to handle temporal or sequential processes. Therefore, it was suggested that a good working hypothesis for future research on the functional differences between the left and the right hemispheres is one in which the left hemisphere would be designated as "temporal" and the right, as "non-temporal."

Dichotic listening studies in patients with complete surgical division of the forebrain commissures showed that the right hemisphere is capable of comprehension and manual expression of verbs and verbal actions. This finding is a reminder that whatever labels are attached to the special abilities of the left and right hemispheres, there is a great deal of overlap of behavioral performance. It remains to be seen whether this redundancy is a contradiction of the idea that the two hemispheres are separately organized, or whether speech comprehension can be processed "non-temporally" as well as "temporally." It is not unreasonalbe to suggest that both hemispheres process all stimuli but each according to its own organizational structure.

The separate organization of the contralateral and ipsilateral auditory pathways to one hemisphere were also studied. Words were repeated faster from the right ear than from the left. It was suggested that this difference was reflective of a memory retrieval process since no ear differences were found for a perceptual task. One might expect from the conclusions on musical expression in the initial part of this Thesis that the ear dominance might be reversed for response times if measured for singing rather than speaking. Preliminary indications are that this is so. When words and tones were presented in the same test, the right ear was faster for words and the left ear was faster for tones. However, more controls are needed before these results can be validated. In any case, it is felt that response time measurements have proved to be a valuable tool for tracking down the organizational parts of the auditory system.

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