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Recognition Memory for Text and Melody of Songs After Unilateral Temporal Lobe Lesion: Evidence for Dual Encoding

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The role of left and right temporal lobes in memory for songs (words sung to a tune) was investigated. Patients who had undergone focal cerebral excision for the relief of intractable epilepsy along with normal control subjects were tested in 2 recognition memory tasks. The goal of Experiment 1 was to examine recognition of words and of tunes when they were presented together in an unfamiliar song. In Experiment 2, memory for spoken words and tunes sung without words was independently tested in 2 separate recognition tasks. The results clearly showed (a) a deficit after left temporal lobectomy in recognition of text whether sung to a tune or spoken without musical accompaniment, (b) impaired melody recognition when the tune was sung with new words following left or right temporal lobectomy and (c) impaired melody recognition in the absence of lyrics following right but not left temporal lobectomy. The different role of each temporal lobe in memorizing songs provides evidence for the use of dual memory codes. The verbal code is consistently related to left temporal lobe structures, whereas the melodic code may depend on either or both temporal lobe mechanisms, according to the type of encoding involved.

The concept of dual encoding in memory has been the focus of considerable interest in cognitive psychology. Several authors (Bower, 1972; Paivio, 1969; Paivio & Csapo, 1973) have argued that the availability of both verbal and pictorial codes enhances recall of representational drawings and concrete words. There is also evidence that auditory imagery can be important if the referent of a word is primarily perceived in the auditory modality (Geiselman & Bjork, 1980; Geiselman & Glenny, 1977; Paivio, 1989). Despite considerable research into encoding mechanisms in memory, however, the neural substrate underlying multiple encoding of information is still largely unknown. The study of patients with focal brain lesions may help to clarify this issue by revealing selective disruption of the use of specific memory codes. The goal of the present study is to investigate the possibility of dual encoding in memory for auditory information by testing recognition of tunes and words in songs. Examination of the effects of unilateral temporal lobe lesions on memory for such dual-encodable stimuli may provide an opportunity to elucidate the interplay between verbal and melodic codes in memory.

Evidence for a dissociation between the role of the left and the right temporal lobes in verbal and imaginal encoding of verbal stimuli has already been reported in the visual modality. For example, Jones-Gotman and Milner (1978) showed that the ability to profit from visual imagery as mediator in a verbal learning task was impaired in patients with right temporal lobe lesions. Whitehouse (1981) also provided convergent evidence in favor of hemispheric specialization in imaginal and verbal memory coding.

There is also evidence for the existence of two separate functional mechanisms for the retention of verbal and tonal information. For example, short-term retention of tonal information seems to be less affected by verbal than by tonal interference presented between a target and a comparison tone (Deutsch, 1972). A dissociation between these two types of processing and the involvement of each cerebral hemisphere was reported by Bartholomeus (1974), who presented sung letter sequences in a dichotic listening task. She found a right-ear advantage, suggesting predominant left-hemisphere involvement for recognition of verbal sequences, contrasting with a left-ear advantage indicating right-hemisphere superiority for the recognition of the melodic line.

Neuropsychological findings in patients with temporal lobe excisions have also provided evidence for the existence of different memory codes for verbal information and complex auditory patterns. The subjects tested in these studies had undergone anterior temporal lobectomy for the relief of in-

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tractable seizures. Such patients usually do not suffer from gross intellectual disturbance and do not present hemiparesis, hemianopsia, or aphasia. However, they typically display relatively subtle perceptual and memory deficits as a consequence of the temporal lobe lesion. There is much evidence of the predominant role of the left temporal region in various verbal memory tasks (Meyer & Yates, 1955; Milner, 1958, 1967, 1975). On the other hand, a major contribution of the right temporal lobe in various types of musical perceptual tasks, such as melodic discrimination, has been reported (Milner, 1962; Samson & Zatorre, 1988; Zatorre, 1985). However, both temporal lobes appear to be important in memory tasks requiring the recognition of unfamiliar melodies (Zatorre, 1985) and bird songs (Milner, Kimura, & Taylor, 1965), indicating that memory for melody may not be a clearly lateralized cerebral function.

Songs provide a particularly good opportunity to study verbal and melodic memory systems. Serafine, Crowder, and Repp (1984) investigated the degree to which the two components of a song, the melody and the text, are associated in memory for normal subjects. For this purpose, they presented a set of unfamiliar target songs, followed by a recognition task, in which same (old) or different (new) songs were played. The new songs could differ from the target songs by either the words, the tune, both words and tune, or finally, by the fact that the words and the tune had already been heard in two different target songs but were now presented as part of the same song, which was termed the *mismatch* condition.

On the basis of the recognition rates obtained in different conditions, Serafine et al. (1984) argued in favor of an integration of words and tunes in memory for songs. The major evidence came from the comparison of two conditions, a true old song and a mismatch song. They found that an old song response was given more frequently to a true old song than to a mismatch song, even if the melody and the text of both types of song had been heard before. In addition, tunes were better recognized in old songs than in mismatch songs or songs with new words. Recognition of words was generally very good, which tended to disconfirm their hypothesis, but this result was explained by a ceiling effect. However, findings reported in subsequent experiments when the instructions were manipulated (Serafine et al., 1984, Experiment 2) or when the text of the song was replaced by nonsense words (Serafine, Davidson, Crowder, & Repp, 1986) gave further support to the hypothesis of an association between words and tunes in memory for song. In a more recent study, Crowder, Serafine, and Repp (1990) proposed that the integration effect could be partly explained by the physical interaction between the words and the melody (i.e., the identity of a melody can be changed by different phonetic patterns) and also by the temporal contiguity existing between the two components of a song.

In brain-damaged subjects, memory for song has only been investigated by the use of familiar tunes presented without any lyrics, but the data are conflicting. Some results have suggested the predominant contribution of the right hemisphere (Shapiro, Grossman, & Gardner, 1981), others the importance of left-hemisphere structures (Zatorre, 1984), while still others have emphasized the role of both right and left hemispheres (Gardner, Silverman, Denes, Semenza, & Rosensteil, 1977; Grossman, Shapiro, & Gardner, 1981; Shankweiler, 1966) in recognizing melodies. Because familiar songs have been generally learned in the presence of the words, they may have been encoded in memory in two different ways. One may propose on intuitive grounds that the recall of a familiar song can be accomplished by means of either musical or verbal cues. A frequent, though not a necessary, concomitant of familiarity is the possibility that the verbal content associated with the familiar melodies is used even if no lyrics are present. Therefore, tasks requiring recognition of familiar tunes could involve left- as well as right-hemisphere functions, depending on the availability of the verbal cues or on the relative salience of the tunes.

The bilateral contribution of hemispheric mechanisms in memory for familiar tunes may reflect the use of a dual-memory code. Both cerebral hemispheres may contain representational systems necessary for tune recognition. This could explain the apparent contradictions in the literature. The left hemisphere might be more specialized in processing tunes associated with words, whereas the right hemisphere might be more important in processing tunes per se. However, an alternative hypothesis can also be proposed. The role of both right and left hemispheres in recognizing familiar tunes could be attributed to the activation of only one melodic memory code, which is mediated by a bilateral neural mechanism.

In the present study, we tested tune and word recognition in patients with right or left temporal lobe lesions and in normal control subjects to better define the cerebral mechanisms underlying memory for the verbal and melodic components of a song. Analysis of the performance of brain-damaged subjects will allow us to draw inferences about the cognitive representation of songs and about the use of dual-memory codes. If the two components are integrated in memory, one may ask if it is the result of the contribution of the right, left, or both temporal lobe structures. The two components of a song could have been encoded as a single event (i.e., text sung to a melody), or as two separate events mapping onto structures within each cerebral hemisphere. If text and melody are encoded independently, we predict that a left temporal lobe lesion will impair the recognition of text, whereas a right temporal lobe lesion will impair the recognition of tune.

Experiment 1: Memory for Song

Method

Subjects

Forty-three subjects who had undergone a left temporal lobectomy (LT; $n = 22$) or a right temporal lobectomy (RT; $n = 21$) for the relief of intractable epilepsy at the Montreal Neurological Hospital were tested, as well as a group of 20 normal control (NC) subjects.

Except where noted, the epileptogenic lesions were static and of an atrophic nature. The temporal lobe excisions always included structures anterior to Heschl's gyrus and the hippocampus, involving the entirety of the amygdala, the temporal pole, and the anterior neocortex. However, these resections varied in the amount of Heschl's gyrus (primary auditory cortex), hippocampus, and parahippocampal gyrus included in the removal. Classification of lesion extent was based on the surgeon's drawings and report at the time of operation. Figure 1 shows representative examples of left and right temporal lobectomies.

The patients included in this study were either known to have speech lateralized to the left cerebral hemisphere by means of intracarotid sodium Amytal studies ($n = 16$; Wada & Rasmussen, 1960), or this was presumed based on righthandedness and dichotic listening measures (Zatorre, 1989) for the remaining cases. All subjects with known atypical language representation (bilateral or right hemisphere) were excluded. Other criteria for exclusion included radiological or electrographic evidence of either diffuse or bilateral cerebral damage, damage outside the temporal lobe, or neurological signs such as aphasia, hemiparesis, or hemianopsia. Also excluded were patients with a Full Scale IQ (nearest to the time of experimental testing) of less than 75 on the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 1981).

Musical experience was balanced among the groups of subjects. Each subject was assigned to one of three categories corresponding to his musical experience. The first category included subjects with no musical background; the second one included subjects with less than 2 years of any type of musical training, and with no current practice; the third one included subjects with more than 2 years of musical training as well as subjects who continued to practice occasionally. More than two thirds of the subjects in each group had little or no musical experience (i.e., corresponding to the first two categories), and no professional musician participated in this study. All subjects were native English speakers or bilinguals with English as their primary language.

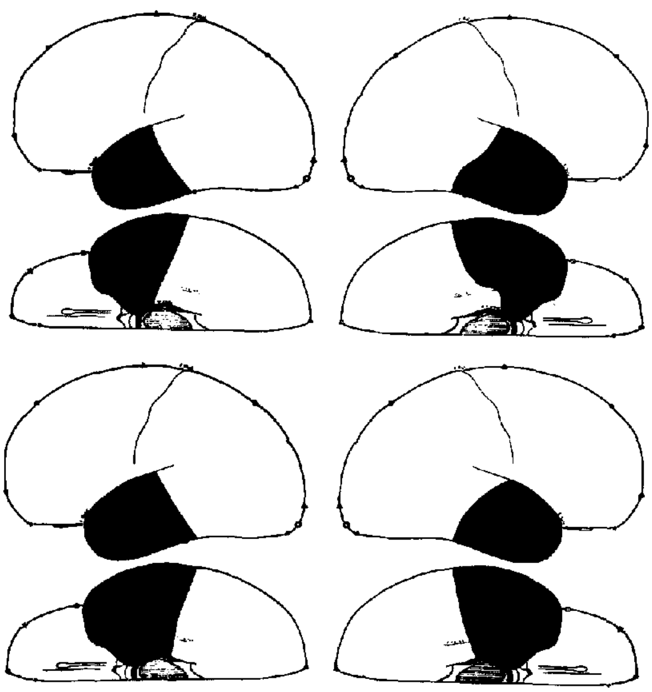

Figure 1. Standard lateral and ventral diagrams of the cerebral hemispheres that depict the surgeon's estimate of the left and right temporal lobe resection for two representative cases. (The lateral surface is shown above and the ventral surface is shown below for each case. The upper maps represent small hippocampal removal, and the lower maps represent large hippocampal removal.)

Table 1 presents the sex distribution, mean age, and mean years of education for each group as well as WAIS-R Full Scale IQ values for the patient groups. Separate analyses of variance (ANOVAs) did not show any significant difference between the groups of subjects in terms of age, $F(2, 60) = 1.79$; $MS_e = 65.43$; $p = .17$, or educational level, $F(2, 60) = 2.43$, $MS_e = 5.69$; $p = .10$. There was also no significant difference between the patient groups in Full Scale IQ $F(1, 41) = 0.15$; $MS_e = 204.24$; $p = .70$. Table 2 displays additional neuropsychological test data for the patient groups: mean digit span (forward and backward), along with the results for the immediate and delayed recall of verbal passages, paired-associate words, and simple visual designs from the Wechsler Memory Scale (Wechsler, 1945). Separate ANOVAs with one between factor (group: RT vs. LT) and one within factor (condition: immediate vs. delayed) were carried out for each of the memory tasks. The ANOVA carried out on the digit span revealed no main effect or interaction. There was a significant main effect of condition, such that the immediate condition was easier than the delay condition in the recall of stories, $F(1, 41) = 138.5$; $MS_e = 4.51$; $p < .0001$, words, $F = 198.9$; $MS_e = 3.27$; $p < .0001$, and visual designs, $F = 35.81$; $MS_e = 3.39$; $p < .0001$. There was also a main effect of group in the recall of stories, $F = 13.42$; $MS_e = 66.10$; $p < .001$, and in the recall of paired-associate words, $F = 19.43$; $MS_e = 20.18$; $p = .0001$. The subjects in the LT group recalled fewer items than the subjects in the RT group ($p < .01$). Finally, there was a Group × Condition interaction in the recall of paired-associate words, $F(1, 41) = 6.27$; $MS_e = 3.27$; $p = .01$. There was no other main effect or interaction in these analyses. These results indicate the presence of verbal memory deficits characteristic of lesions in the left temporal lobe, which contrast with the normal IQ, digit span, and visual memory abilities.

Left temporal lobe group. The mean extent of neocortical excision was 4.8 cm from the temporal pole and along the Sylvian Fissure (range: 4.0–6.0) and 4.8 cm along the base (range: 4.0–6.0). Seven of the 22 patients had a large removal of the hippocampus, including more than 1.5 cm of the hippocampus. The remaining cases had undergone either a small (less than 1.5 cm) or no excision of the hippocampus. A partial or complete removal of the transverse gyri of Heschl was carried out in 6 subjects. This area was spared in the other cases. Fourteen patients were tested 2 weeks postoperatively, whereas the remaining patients were tested during follow-up evaluation 1 or more years after the operation.[1]

Right temporal lobe group. The mean extent of neocortical excision was 5.3 cm along the Sylvian Fissure (range: 4.0–7.5) and 5.7 cm along the base (range: 4.5–9.0). Eight of the 21 patients had an extensive removal of the hippocampus and parahippocampal gyrus, whereas the remaining cases had a small resection of those structures. Ten patients had a partial or complete removal of the transverse gyri of Heschl. Nine patients were tested 2 weeks postoperatively, whereas the remaining cases were tested during follow-up studies.[2]

Normal control group. Twenty right-handed normal control subjects without known neurological problems were also tested. These subjects, drawn from hospital staff and patients' families, were matched to the patient groups with respect to sex, age, educational level, and musical experience.

Material

The experimental materials were taken from a study by Serafine et al. (1984) in which their actual tapes were used. The stimuli

[1] The LT group included one case of astrocytoma, one case of ganglioglioma, and one case of angioma.

[2] The RT group included one case of astrocytoma and one case of ganglioglioma.

Table 1
Experiment 1: Characteristics of Subjects; Sex Distribution and Mean Age, Education and Full Scale Wechsler IQ (FSIQ) (Range in Parentheses)

Group	Sex M	Sex F	Age (in years)	Education (in years)	FSIQ
NC	8	12	31.4 (21–54)	14.2 (11–17)	—
LT	11	11	27.0 (16–45)	14.1 (11–20)	101 (76–130)
RT	11	10	30.4 (17–45)	12.6 (7–18)	102 (80–129)

Note. NC = normal control. LT = left temporal. RT = right temporal.

consisted of 20 pairs of unfamiliar song excerpts of 5-s duration on average, with interchangeable text and tune drawn from an American folk-song repertory.

Most of the song excerpts were considered unfamiliar by all the subjects. On average, no more than 1 song was recognized by each subject during the initial presentation of the stimuli as being familiar. Half of the songs were the original songs, whereas the other half consisted of tunes matched with words drawn from the paired songs. Each pair of songs yielded four different items. The 80 different songs thus generated were sung by a tenor with vocal training without instrumental accompaniment and recorded on audio tape.

In the presentation phase of the test, 24 songs were played one time each with a 5-s interval between successive presentation items. In the recognition test, 20 songs separated by a 10-s interval were presented. These were distributed into five experimental conditions, four trials per condition for a total of 20 items. One of the five conditions was old songs, that is, excerpts previously heard in the first part of the test. The other four conditions were all new songs consisting of: (a) old words paired with a new tune, (b) an old tune paired with new words, (c) excerpts where neither the words nor the tune had already been presented, and (d) a mismatch condition composed of the words previously heard in 1 song although the tune was originally presented in another song. Note that a mismatch test item required two presentation items, which accounts for the 24 songs in the presentation phase (examples in Figures 2 and 3). Five different versions of the test were used for counterbalancing the order of presentation of the different experimental conditions, as well as which songs were tested as old songs and how the words and tunes were recombined to form new songs. Across the five different versions, each presentation item was tested in each of the five experimental conditions. In each group of subjects, 4 subjects were tested in each of the five versions, except in the RT group in which 5 subjects were assigned to Version 2 and in the LT group in which 5 subjects were assigned to Version 3.

Procedure

Each subject was tested individually and told that his or her memory for songs would be tested. The subject received the following instructions:

> This is a test to see how well you are able to remember songs. A song in this test refers to both the words that are sung and to the tune, or melody and rhythms. During the first part of the test you will hear a series of short song excerpts sung by a young man without any instrumental accompaniment. These are not very well-known songs, so probably none of them will be familiar to you. All you have to do for now is listen carefully to each song excerpt as it is played, and try to remember the songs, because you will be asked to recognize them later, as well as the words and the tunes. Do you have any questions?

After the presentation of the 24 target songs, the subject was asked, "Did any of those songs seem familiar? (i.e., Have you ever heard any of them before?). If so, how many?"

Then the following instructions were given:

> Now comes the hard part. You are now going to hear some more songs. Some will be the same songs you heard earlier, others will be different. You have to answer the following questions each time:
>
> 1) Have you heard exactly the same song during the first part of the test (same words sung to the same tune)?
>
> 2) Have you heard these words before on the first tape (perhaps sung to a different tune)?
>
> 3) Have you heard this tune before on the first tape (perhaps sung to different words)?
>
> Note that is is possible that you may have heard both the words and the tune before, but not sung together in the same song. In that case you would answer "no" to the first question, and "yes" to the two following questions. This is a difficult test. You may have to guess sometimes, but try to make the best guess you can for each question. If you do not have any questions we will proceed.

Results and Discussion

The two principal dependent variables used in the following analyses are the mean percentage of correct recognition of words and tune, which correspond to the number of correctly classified old and new stimuli. A preliminary ANOVA indicated that there were no effects of sex, $F(1, 57) = 1.49$, $MS_e = 0.01$, $p = .23$, musical experience, $F(2, 52) = 0.75$; $MS_e = 0.02$; $p = .48$, test version, $F(4, 48) = 0.97$; $MS_e = 0.02$; $p =$

Table 2
Experiment 1: Attentional and Memory Scores

Group	Span F	Span B	Stories Immediate	Stories Delay	P. A. words Immediate	P. A. words Delay	Visual designs Immediate	Visual designs Delay
LT	7 (4–8)	5 (2–8)	13 (5.5–24)	7 (0–17)	10 (2–19)	5 (1–10)	12 (6–14)	9 (1.5–14)
RT	6 (4–8)	5 (3–8)	19 (8–32)	14 (3–29)	15 (8.5–20)	8 (4–10)	11 (6–14)	9 (2–13)

Note. F = mean number of digits repeated forward. B = digits backward. LT = left temporal. RT = right temporal. PA = paired associate.

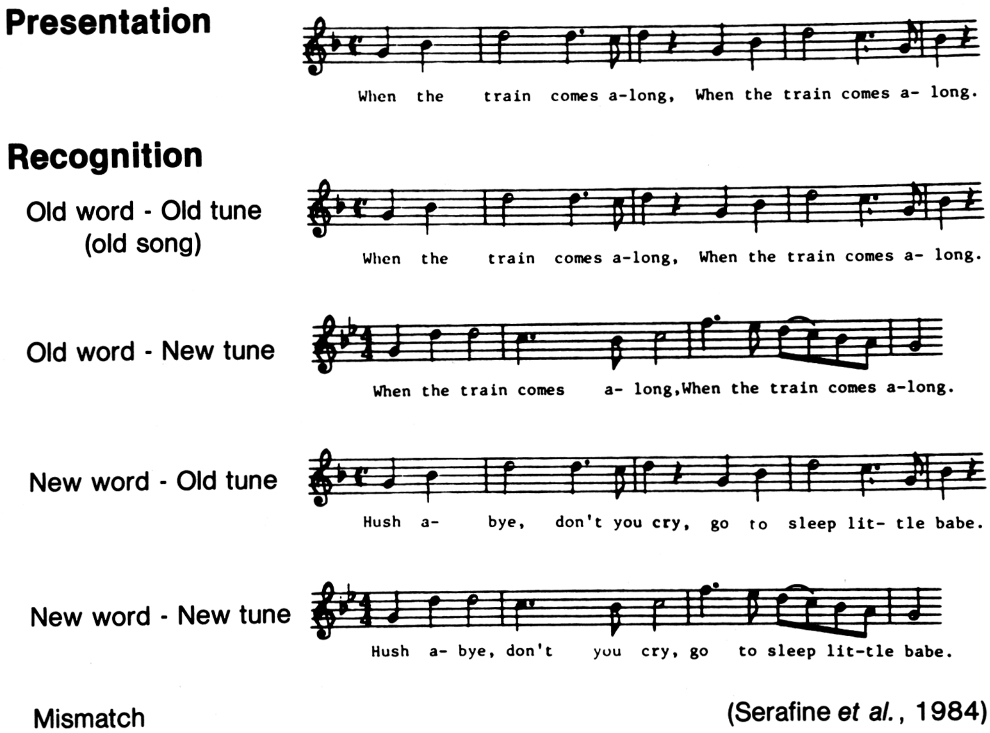

Figure 2. Experiment 1: Example of a target song with 5 conditions used in the recognition test (The mismatch condition is depicted in Figure 3.). *Note.* From "Integration of Melody and Text in Memory for Songs" by M. L. Serafine, R. G. Crowder, and B. H. Repp, 1984, *Cognition, 16,* p. 289. Copyright 1990 by Elsevier Science Publishers. Adapted by permission.

.43, or time of testing (postoperative vs. follow-up; $F(1, 38) = 0.01$; $MS_e = 0.02$; $p = .92$, on performance. However, a significant Group × Time of Testing interaction was found, $F(1, 38) = 5.32$; $MS_e = 0.02$; $p < .05$. During the postoperative assessment the subjects in the LT group were more impaired in overall performance than the subjects in the RT group ($p < .05$), whereas there was no such difference during the follow-up evaluation. However, the performance of subjects in the LT group did not differ significantly between the postoperative and the follow-up testing.

Recognition of Words and Tunes

Table 3 shows the mean proportion of old tune and old word responses made to the five different conditions.[3] The mismatch condition corresponds to a new song with old words and an old tune.

To test for a dissociation between a deficit in the recognition of words and tunes and the side of the lesion, we calculated the total number of correct responses given to the 20 test items across the five different conditions for the word and tune recognition tasks for each subject. Figure 4 represents the mean percentage of correct recognition of words and tunes for the three groups of subjects derived from data in Table 3.[4] The figure shows that performance of subjects with temporal lobe lesions is lower than normal control performance. However, scores obtained by subjects with LT lesions in recognition of words and tunes are lower than scores obtained by subjects with RT lesions. For all subjects, the words are better recognized than the tunes.

An ANOVA with one repeated measure (material) and one between-subjects factor (group: NC, LT, and RT) was carried out on the mean percentage of correct recognition of words and tune for the three groups of subjects. The results showed a significant group effect, $F(2, 60) = 6.42$; $MS_e = 0.01$; $p < .005$. Post hoc statistical analysis by Newman-Keuls comparisons showed that the LT group was significantly impaired overall as compared with the NC group ($p < .01$), whereas the RT group did not differ significantly from the NC group. This finding indicates that structures within the left temporal lobe mediate memory for both melodic and lyrical components of a song. We do not believe that this deficit of subjects in the LT group can be attributed to a generalized cognitive impairment because they obtained normal IQ scores; furthermore, there is no evidence of global memory disturbance in this group but only deficits in verbal recall typical of LT lobe lesion, as documented in Tables 1 and 2.

[3] In most cases, no internally inconsistent responses were detected in the data, such that the subject answered "yes" to the first question but failed to give a positive response to one of the following questions. Only three such responses were found in the LT group, one in the RT group, and two in the NC group.

[4] The mean percentage of correct recognition of words and tunes corresponds to the average of the two hit rates, one minus each of the two false alarm rates, and the hit rate for the old songs.

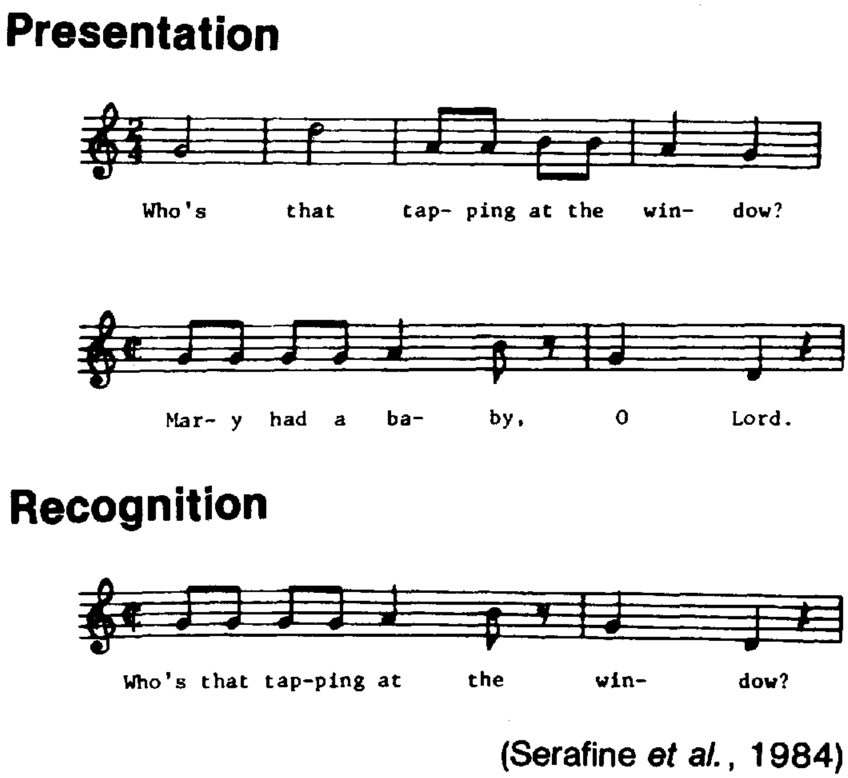

Figure 3. Experiment 1: Example of a mismatch condition.

We also observed a significant effect of material, $F(1, 60) = 38.86$; $MS_e = 0.01$; $p = .0001$. In agreement with the finding of Serafine et al. (1984, 1986), the words (average of 71% correct responses) were better recognized than the tunes (average of 60% correct responses). However, there was no significant Group × Material interaction, $F(2, 60) = 0.26$; $MS_e = 0.01$; $p = .77$.

To be more confident of these results and to exclude the possibility of a response bias, we carried out an additional ANOVA on the mean proportion of old word and old tune responses made to the five different conditions (Table 3).[5] The proportion of hits (old word and old tune responses given to an old stimulus) and false alarms (old word and old tune responses given to a new stimulus) was calculated across all test items for each subject. As expected, this ANOVA with one between-subject factor (group: NC, LT, and RT) and two within-subject factors (material: word and tune; and trial type: old and new items) essentially replicated the previous results. In addition, a significant main effect of trial type, $F(1, 60) = 179.57$; $MS_e = 0.03$; $p < .0001$, was obtained because all groups made substantially more hits than false alarms. There was also a significant Group × Trial Type interaction, $F(2, 60) = 6.97$; $MS_e = 0.03$; $p < .005$. According to Newman-Keuls comparisons, subjects in the LT group made significantly more false alarms to both types of stimuli than subjects in the NC group ($p < .01$), whereas there was no significant difference between the RT and NC groups ($p > .05$). The number of hits did not differ significantly between the LT and the NC groups ($p > .05$), or between the RT and the NC groups ($p > .05$). Note, however, that the LT group had a somewhat lower hit rate than the NC group, which argues against an overall response bias as an explanation of their poorer performance. There was also a significant effect of material, $F(1, 60) = 71.14$; $MS_e = 0.04$; $p < .0001$, as well as a Material × Trial Type interaction, $F(1, 60) = 76.04$; $MS_e = 0.02$; $p < .0001$.

The deficit of subjects with LT lobectomy in word recognition confirms the important contribution of left temporal lobe structures in memory for text. The major role of the left temporal lobe in melodic memory can be explained in two different ways. First, it is possible that the left temporal lobe is involved in mediating tune recognition independently of the verbal encoding. Second, this finding could be attributed to the importance of verbal cues in addition to melodic memory in recognition. To be sure that subjects were basing their judgments only on the tune, a subsequent analysis was performed on old tune responses given to conditions in which the words had never been presented before (i.e., new words).

Recognition of tune and words when the other component is new. We predicted that only subjects with right temporal lobe lesions would present a deficit in retrieval of tunes in the condition in which the words are present but irrelevant. Conversely, we predicted that recognition of words when tunes are useless would be impaired after a left temporal lobectomy.

To verify these predictions, we analyzed the proportion of old tune responses by considering only the trials in which

[5] We were not able to use an unbiased measure such as d' because of the low number of items for each condition.

Table 3
Experiment 1: Mean Proportion of Old Tune and Old Word Responses for the NC, LT, and RT Subjects

New songs	Old tune responses: New words	Old tune responses: Old words	M	Old word responses: New words	Old word responses: Old words	M
			NC			
New tune	0.36	0.64	0.50	0.14	**0.56**	0.35
Old tune	**0.65**	**0.73**	**0.69**	0.10	**0.70**	0.40
M	0.50	0.67	—	0.12	**0.63**	—
Old songs			**0.86**			**0.75**
			LT			
New songs						
New tune	0.55	0.65	0.60	0.31	**0.66**	0.46
Old tune	**0.53**	**0.66**	**0.60**	0.28	**0.58**	0.43
M	0.50	0.67	—	0.29	**0.62**	—
Old songs			**0.80**			**0.63**
			RT			
New songs						
New tune	0.54	0.62	0.58	0.20	**0.49**	0.34
Old tune	**0.55**	**0.69**	**0.62**	0.11	**0.69**	0.40
M	0.54	0.65	—	0.15	**0.59**	—
Old songs			**0.88**			**0.71**

Note. Hits (old responses to previously presented stimuli) are shown in bold. NC = normal control. LT = left temporal. RT = right temporal.

tunes were presented with new words (i.e., in Table 3: items with old tune and new words: Hit, vs. items with new tune and new words: False alarm). The analysis revealed no main effect, but a Group × Trial Type interaction was found, $F(2, 60) = 3.48$; $MS_e = 0.08$; $p < .05$. Post hoc statistical analysis by Newman-Keuls comparisons showed that the subjects in the NC group made substantially more old tune responses to old (hits) than to new (false alarms) stimuli ($p < .05$). However, this difference did not reach significant level in the

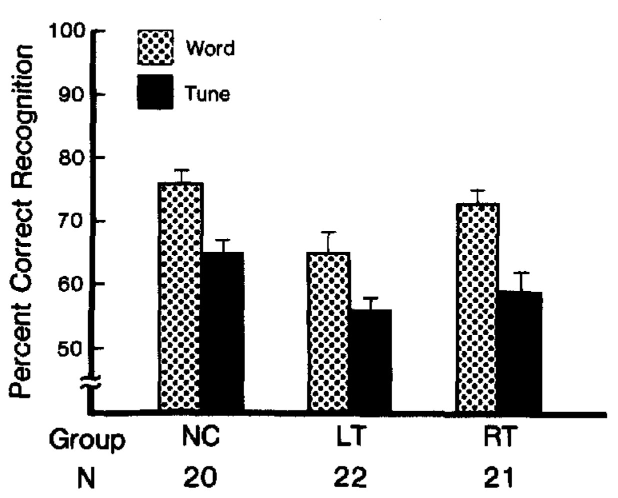

Figure 4. Experiment 1: Mean % correct responses in recognition of words versus tunes by the three groups of subjects. (Here, and in subsequent bar graphs, the line on each bar represents the standard error of the mean.)

performance of subjects in the RT ($p > .05$) or the LT ($p > .05$) groups, excluding therefore the presence of a response bias in the patient results. In fact, performance of both patient groups was essentially at chance for tune recognition.

This latter result suggests that, contrary to our predictions, recognition of tunes is markedly impaired after both right and left temporal lobe lesions. The contribution of the right temporal lobe in memorizing tunes obtained in this latter analysis was not demonstrated in the first analysis, in which the recognition of tunes may have been mediated by the verbal content of the song. This finding therefore indicates a role for the right temporal lobe in memory for tunes only when the words are irrelevant (or new), whereas the role of the left temporal lobe seems to be related to the presence of the words in general.

A complementary analysis was performed on the proportion of old word responses given to trials in which words were presented with new tunes (i.e., items with old words and new tune: Hit, vs. items with new words and new tune: False alarm). The results showed a significant main effect of group, $F(2, 60) = 3.36$; $MS_e = 0.08$; $p < .05$, but no other main effect or interaction. Post hoc statistical analysis by Newman-Keuls showed that subjects in the LT group gave significantly more old word responses than subjects in the NC ($p < .05$) and the RT ($p < .05$) groups for both trial types, suggesting in this one instance the presence of a response bias in the LT group (i.e., increase of hits as well as false alarms).

Integration Effect

Subsequent ANOVAs were carried out to verify that our results are consistent with the results obtained by Serafine et al. (1984) in normal subjects.[6] They proposed that text and tune are integrated in memory for songs mainly on the basis of the responses given to an old song and to a mismatch song. We therefore compared the number of old song (Table 4), old word, and old tune responses (the two latter are in Table 3) in an old song and in a mismatch song in three separate analyses with one repeated factor (condition: old song vs. mismatch song) and one between-subject factor (group). The first analysis was carried out on the proportion of positive responses given to the question "Have you heard exactly the same song before?" The results showed a significant effect of condition, $F(1, 60) = 10.90$; $MS_e = 0.05$; $p < .002$, but no other main effect or interaction. All subjects gave more positive responses to an old song (62% positive) than to a mismatch song (48% positive).

The next ANOVA was performed on the proportion of old word responses under the old song and the mismatch condi-

[6] Although the overall results of the NC subjects obtained in our study and in Serafine's study followed the same pattern, the subjects that we tested had somewhat lower overall scores. Serafine and collaborators tested undergraduate students from Yale University, whereas we tested subjects who were not so selected in terms of intellectual abilities. They were drawn from hospital staff and patients' families to match the patients as well as possible. Therefore, the difference between the performance of the two groups of subjects could be attributed to this factor.

Table 4
Experiment 1: Mean Proportion of Old Song Responses for the NC, LT, and RT Subjects

Songs	Words: New	Words: Old	*M*
	NC		
New			
New tune	0.04	0.34	0.19
Old tune	0.08	0.48	0.28
M	0.06	0.41	—
Old			**0.66**
	LT		
New			
New tune	0.20	0.39	0.29
Old tune	0.22	0.48	0.35
M	0.21	0.43	—
Old			**0.55**
	RT		
New			
New tune	0.12	0.33	0.22
Old tune	0.06	0.50	0.28
M	0.09	0.41	—
Old			**0.64**

Note. Hits are shown in bold.

tions. This analysis revealed no interaction or main effects. The responses to words by all the subjects in an old song (69% positive) and in a mismatch song (65% positive) did not differ significantly. Finally, we considered the proportion of old tune responses. The results showed a significant effect of condition, $F(1, 60) = 15.75$; $MS_e = 0.05$; $p < .0005$). All subjects were more likely to answer yes in an old song (85% positive) than in a mismatch song (69% positive). In other words, the subjects recognized tunes presented with their original companion better than tunes matched with words borrowed from another song previously heard. Note that in this comparison the words had been heard in both old song and mismatch conditions and therefore could not confound the responses.

These results are in agreement with the data of Serafine et al. (1984, 1986) and support their hypothesis that text and tune are integrated to some extent in memory for song. In addition, we found no interaction between the factors group and condition, suggesting that integration seems to take place for all subject groups. However, the lack of significant effect between the recognition of words in an old song and in a mismatch song cannot be attributed to a ceiling effect (as proposed by Serafine et al., 1984) because performance was relatively low. We can therefore hypothesize that words can be stored independently from the tune in these songs.

Effect of Heschl's gyri and hippocampal removal. To test the effect of the removal of Heschl's gyrus (the primary auditory cortex) and the effect of the resection of the hippocampus on the recognition of words and tune, two ANOVAs were performed with two between-subjects factors (group and size of the removal) and one within-subjects factor (material). No effects of resection of the primary auditory cortex, $F(1, 39) = .79$; $MS_e = 0.02$; $p = .38$, or of the hippocampal area, $F(1, 38) = 2.15$; $MS_e = 0.02$; $p = .15$, were found on any of the dependent variables. These results suggest that resection of the primary auditory cortex as well as the amount of hippocampal structures removed did not significantly affect performance. Previous studies have shown that in certain particular tasks the excision of the hippocampus produced specific memory deficits, whereas in others, memory impairments were not related to the size of the hippocampal excision (for review, see Jones-Gotman, 1987). To date, the role of medial temporal lobe structures in memory for nonverbal auditory stimuli, and more specifically for melodies, has never been documented in human subjects. However, all subjects in the present study had the amygdala removed, and most had a small hippocampal removal. It seems possible, therefore, that an excision of the most anterior medial temporal region, together with removal of lateral neocortex, is enough to yield a deficit.

Experiment 2: Separate Presentation of Words and Tunes

One difficult question remains unanswered. Is there a difference in memory for tunes between conditions in which the words are present but irrelevant and conditions in which the words are absent? Results from Experiment 1 suggest that the left temporal lobe contribution in tune recognition may be related to the presence of lyrics even when they are not relevant to solving the task, whereas the right temporal lobe seems to be predominantly involved in melodic processing per se.

We therefore decided to carry out a second experiment to try to specify the role of the right as opposed to the left temporal lobe in memory for tunes without any lyrics. The goal of the second experiment is to clarify the encoding of text and tune presented separately in two different tasks, as opposed to the encoding of the same stimuli presented together in a song. If distinct cortical structures are involved in verbal and melodic encoding, the recognition of the verbal or the melodic component of the song presented separately in two memory tasks should require a different contribution of the left and the right temporal lobe.

For this purpose, two new groups of patients with right or left temporal lobectomy as well as a new group of normal control subjects were tested in two memory tests. One test consists of the presentation of the tunes from the first experiment without any words at all. The other test is composed of the words alone, spoken without any musical accompaniment. We predicted that only subjects with right temporal lobe lesions would be impaired in memory for tunes, whereas subjects with left temporal lobe lesions would show a deficit in word recognition.

Method

Subjects

Twenty-four English-speaking subjects who had undergone a left ($n = 12$) or a right ($n = 12$) anterior temporal lobectomy as well as

10 normal control subjects were tested. None of the subjects who participated in the previous study were tested in this experiment.

Table 5 presents the sex distribution, mean age, and mean number of years of education for each group as well as the Full Scale IQ for the patient groups.

Separate ANOVAs did not show any significant difference between the groups of subjects in terms of age, $F(2, 30) = 0.25$; $MS_e = 47.8$; $p = .78$, or educational level, $F(2, 31) = 1.51$; $MS_e = 3.7$; $p = .24$, but the Full Scale IQ of subjects with RT lobe lesions was significantly lower than that of subjects with LT lobe lesions, $F(1, 22) = 11.52$; $MS_e = 71.9$; $p < .005$.

Left temporal lobe group. The mean extent of neocortical excision was 4.7 cm along the Sylvian Fissure (range: 4.0–5.0) and 5.1 cm along the base (range: 4.5–6.0). Five subjects had more than 1.5 cm of hippocampus removed, and the other 7 patients had undergone either a small or no excision of the hippocampus. The removal did not encroach upon the transverse gyri of Heschl in eight cases, but it did so in the remaining four cases. Six patients were tested 2 weeks postoperatively, whereas the remaining patients were tested during follow-up evaluation.[7]

Right temporal lobe group. The mean extent of neocortical excision was 5.0 cm along the Sylvian Fissure (range: 3.5–7.1) and 5.8 cm along the base (range: 3.5–7.7). Seven subjects had undergone a large excision, and 5 had undergone a small or no hippocampal excision. There was excision of the transverse gyri of Heschl in only two of these cases. Ten patients were tested 2 weeks postoperatively, whereas the remaining cases were tested during follow-up studies.[8]

Material

The stimuli consisted of the texts and the melodies from the songs presented in Experiment 1 (Serafine et al., 1984). Two distinct memory tasks were designed.

The tune recognition test consisted of the melodies from the stimuli of Experiment 1, sung by a male musician with vocal training, using the syllable *la*.

The word recognition test was composed of the presentation of short sentences spoken by the same person. These verbal stimuli were the same as in the previous experiment, except that instead of being presented in the context of a song, they were spoken without any melodic accompaniment, as if they were speech passages.

Five different versions of the word and the tune recognition tests were prepared as in the first study. Half of the subjects in each group performed the word recognition test first, the other half performed the tune recognition test first.

Table 5
Experiment 2: Characteristics of Subjects; Sex Distribution and Mean Age, Education and Full Scale Wechsler IQ (FSIQ) (Range in Parentheses)

Group	Sex M	Sex F	Age (in years)	Education (in years)	FSIQ
NC	6	4	27.9 (17–39)	13.4 (11–16)	—
LT	7	5	30.0 (16–43)	13.3 (9–16)	99 (91–119)
RT	7	5	29.4 (21–37)	12.1 (9–15)	87 (76–96)

Note. NC = normal control. LT = left temporal. RT = right temporal.

Procedure

Subjects were tested individually and told that their memory for words would be tested in one task whereas their memory for tunes would be tested in another task.

For each task, 24 target items (either spoken words or tunes sung without words) were first presented, followed by the recognition series consisting of 20 items (12 old and 8 new stimuli). In this second part, the subject's task was to answer verbally after the presentation of each stimulus if he or she had heard the item before or not. All other conditions of testing were as in the previous experiment.

Results

The two main dependent variables used in the following analyses are the mean percentage of correct recognition of words and tunes. A preliminary ANOVA indicated that there were no effects of sex, $F(1, 28) = 0.56$; $MS_e = 125.9$; $p = .83$, test version, $F(4, 19) = 1.35$; $MS_e = 136.5$; $p = .29$, or order of presentation of the two tasks, $F(1, 27) = 0.27$; $MS_e = 128.4$; $p = .61$, on performance.

Figure 5 illustrates the mean percentage of correct recognition (i.e., number of correctly recognized and correctly rejected items) obtained in the word and tune memory tasks by the three groups of subjects. As predicted, subjects with LT lobe lesions obtained lower scores in word recognition (79% correct) than subjects with RT lobe lesions (87% correct) or NC subjects (93% correct). By contrast, subjects with RT lobe lesions obtained lower scores in tune recognition (55% correct) than subjects with LT lobe lesions (65% correct) or NC subjects (70% correct).

An ANOVA with one repeated measure (material) and one between-subjects factor (group) was carried out on the mean percentage of correct recognition of words and tunes for the three groups of subjects. The results showed a significant group effect, $F(2, 31) = 5.62$; $MS_e = 117.8$; $p < .01$. We also observed a significant effect of material, $F(1,31) = 81.60$; $MS_e = 105.8$; $p < .0001$. As in Experiment 1, the words were better recognized than the tunes by all the subjects. Finally, the results demonstrated a significant Group × Material interaction, $F(2,31) = 4.45$; $MS_e = 105.8$; $p = .02$. Newman-Keuls comparisons revealed that subjects with LT lobe lesions were significantly impaired in the recognition of words as compared with the NC subjects ($p < .05$), but the difference between subjects in the LT and the RT groups was not significant ($p > .05$). By contrast, subjects with RT lobe lesions demonstrated a significant deficit in tune recognition by comparison with the NC subjects ($p < .01$) and subjects with LT lobe lesions ($p < .05$). Because we found a significant difference between the IQ of the two temporal groups, we carried out an analysis of covariance (ANCOVA) to check if this variable had any effect on the data. The results showed no effect of the covariate, $F(1,21) = 0.80$; $MS_e = 150.1$; $p = .38$, but we found again the interaction between the factors group and material, $F(1, 22) = 7.74$; $MS_e = 121.5$; $p = .01$. We can

[7] The LT group included one case of ganglioglioma.

[8] The RT group included one case of astrocytoma and one case of ganglioglioma.

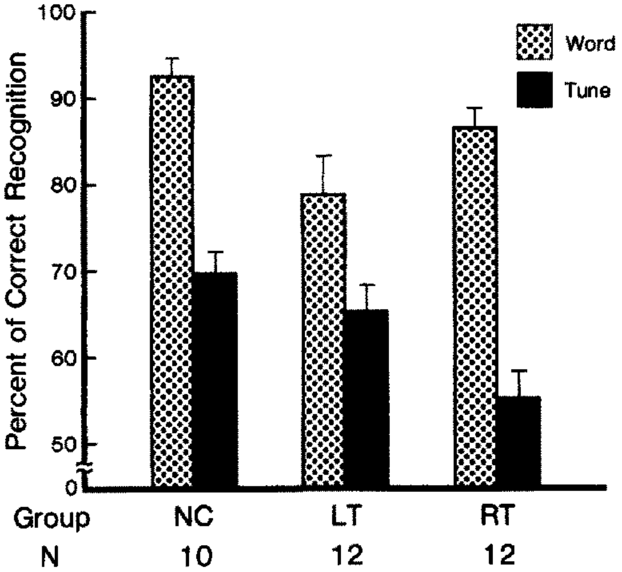

Figure 5. Experiment 2: Mean % correct recognition of words and tunes.

therefore exclude the possibility that the subjects in the RT group were impaired in tune recognition because of their lower IQ.

As in Experiment 1, we performed additional analyses by considering separately the number of old tune and old word responses to an old (hit) or a new (false alarm) stimuli (Table 6).

An ANOVA with one between-subject factor (group) and one within-subject factor (trial type) was carried out on the proportion of old tune responses. The results showed a significant effect of trial type, $F(1, 31) = 225.13$; $MS_e = 1.8$; $p < .0001$, but no effect of group. The proportion of hits was higher than the proportion of false alarms for all the subjects. There was also a significant Group × Trial Type interaction, $F(2, 31) = 4.81$; $MS_e = 1.8$; $p = .01$. According to Newman-Keuls comparisons, subjects in the RT group made significantly more false alarms than subjects in the LT ($p < .05$) and the NC ($p < .01$) groups, whereas the proportion of hits did not differ across the different groups. Once again, note that the hit rate for the RT group was slightly lower than that of the NC subjects, arguing against the presence of a general response bias.

Table 6
Experiment 2: Mean Proportion of Old Tune and Old Word Responses for the NC, LT, and RT Subjects

Subjects	Old tune responses	Old word responses
NC		
New item	28.7	0.0
Old item	**68.3**	**85.0**
LT		
New item	37.5	11.5
Old item	**68.1**	**69.4**
RT		
New item	56.2	7.3
Old item	**66.7**	**80.6**

Note. Hits are shown in bold. NC = normal control. LT = left temporal. RT = right temporal.

A similar analysis was performed on the proportion of old word responses. A significant effect of trial type was obtained, $F(1, 31) = 467.1$; $MS_e = 2.9$; $p < .0001$, the proportion of hits being higher than the proportion of false alarms. There was also a Group × Trial Type interaction, $F(2, 31) = 3.80$; $MS_e = 2.9$; $p < .05$. According to Newman-Keuls comparisons, the number of hits was lower in the LT group than in the NC group ($p < .05$), but there were no significant differences between the LT and the RT groups. On the other hand, the number of false alarms did not differ significantly between the groups, although subjects in the LT group made more false alarms than subjects in the NC group.

To compare the results of Experiments 1 and 2 for the NC subjects, we analyzed separately the percentage of correct recognition of each component. A t test showed that words sung with new tunes (71% correct responses) are more difficult ($t = 3.56$; $p < .01$) to recognize than spoken words (92% correct responses). Although tunes sung with new words (64% correct responses) are also more difficult to recognize than tunes sung using the syllable *la* (70% correct responses), this difference was not significant ($t = 0.95$; $p > .05$).

Discussion

The results of Experiment 2 revealed differential vulnerability of verbal and musical memory to left and right temporal lobe lesions, respectively, thereby demonstrating a double dissociation between specificity of memory disturbance and side of temporal lobectomy. The scores obtained in recognition of text were lower after LT lobectomy, whereas tune recognition was impaired after RT lobectomy. The replication of the results by breaking down the number of hits and false alarms gives further support to the idea that the LT lobe is predominantly involved in verbal memory, whereas the RT lobe has an important role in memory for unfamiliar melodies when the stimuli to be remembered are presented in independent contexts.

The clear lateralized deficit obtained in memorizing nonverbal melodies in this experiment contrasts with previous findings reported by Milner et al. (1965) and by Zatorre (1985), in which the role of both temporal lobes in recognizing melodic stimuli was indicated. In these studies, the target and the foil melodies were very different from each other. In the present investigation, however, target and foil melodies are similar in overall structure and can easily be confused; the most relevant cues to distinguish targets from foils are probably the specific pitch intervals. Therefore, the comparison of such melodies probably requires good perceptual abilities, which are not disturbed after LT lobectomy, at least when the removal does not include Heschl's gyrus (Samson & Zatorre, 1988; Zatorre, 1985). On the other hand, the subjects with RT lobe lesions are unable to perform such tasks very well, and we would propose that this is because of their difficulty in processing pitch interval information.

It is also possible that the deficit in melodic recognition obtained in the present study is related to difficulties in auditory short-term retention. According to recent results (Zatorre & Samson, 1991), right temporal lobectomy is associated with deficits in discrimination of tones separated by interference, suggesting the important role of the right temporal lobe in short-term retention of tonal information. From the present experiment, it is therefore difficult to determine if the melodic recognition impairment results strictly from a memory deficit or if it is the consequence of melodic perceptual or short-term retention disturbances. Moreover, it is quite possible that perceptual and mnemonic factors interact closely in this type of task, so that a disturbance of one would likely affect the other.

General Discussion

The present study investigated the neural mechanism underlying multiple encoding of songs. Recognition of text and tune was tested together in a song, as well as separately in two tasks, to look for a possible dissociation between verbal and musical memory disturbances. Because precisely the same material was used in Experiments 1 and 2, it was possible to compare memory for verbal and musical information that may have been differently encoded in these two contexts. As predicted, and in agreement with much previous data (Meyer & Yates, 1955; Milner, 1958, 1975), results from Experiments 1 and 2 clearly support the predominant involvement of the left temporal lobe in recognition of text, whether sung to a tune or spoken without musical accompaniment.

For recognition of tunes, the contribution of both left and right temporal lobes was documented. In Experiment 1, the role of both temporal lobes was demonstrated in the analysis of items in which the words—though present—were irrelevant to recognize the tunes. In Experiment 2, however, right but not left temporal lobectomy impaired recognition of melodies sung without words.

These results add an interesting point to previous investigations, suggesting the importance of the context in which the tunes were heard, which seems to change the representation of the target melody in memory. This finding is in agreement with recent results reported by Crowder et al. (1990), showing that phonetic properties of different words can change the musical line sufficiently to influence later recognition of the melodies. In the case of a song, the words actually form part of the stimulus that defines the tune. Under these conditions, left temporal lobe memory mechanisms appear to become involved, in addition to those of the right temporal lobe.

This finding may help to clarify certain results reported in the literature. The role of the left hemisphere in recognition of familiar tunes has been demonstrated by several authors, sometimes in addition to the involvement of the right hemisphere (Gardner et al., 1977; Grossman et al., 1981; Shankweiler, 1966; Zatorre, 1984). These different results, in addition to the present one, suggest that the verbal component associated with a familiar tune may have modified the way in which a tune has been encoded in memory.

An alternative hypothesis, one that does not exclude the previous one, could also explain the bilateral contribution of the temporal lobes in memory for song. It is possible that different dimensions of songs are processed by means of the right and the left temporal lobes before forming an integrated central representation. If some of these mechanisms are disturbed, it will result in a poor melodic representation. This might then preclude the subsequent processing of melodies sung with words that would normally contribute to a unitary representation of song in memory.

Another neuropsychological paradigm, the intracarotid injection of sodium amobarbital (Wada & Rasmussen, 1960), resulting in a temporary anesthesia of one cerebral hemisphere, provides some relevant information. This procedure is used on patients who are to undergo neurosurgery to lateralize speech functions or to assess risk to memory (Rasmussen & Milner, 1977). In most cases right-sided injection leads to a deficit in singing familiar tunes, but not to speech disturbance; in some cases, the subject is able to say the words of the song but cannot sing the tune. Left-sided injection produces both speech and song arrest (Borchgrevink, 1980; Zatorre, 1984). However, song seems to recover more quickly than speech in this latter case (Gordon & Bogen, 1974). These results further support the roles of both cerebral hemispheres in singing familiar songs but suggest some degree of functional asymmetry consistent with our findings.

Our results also suggest that the verbal and the melodic memory codes are partially integrated. A complete independence between these two codes would have involved similar patterns of results in Experiments 1 and 2, which is not the case. The results of NC subjects showed that words sung with new tunes are more difficult to recognize than spoken words. It seems that, in general, the verbal and melodic components presented together in a song (Experiment 1) are less accessible in recognition than when they are presented separately in two different memory tasks, which may be interpreted as further evidence for an integration effect (Experiment 2). In accordance with the data of Serafine et al. (1984), our study showed that words, and especially tunes, are better recognized in an old song than in a mismatch song although both words and tunes have already been heard before. Integration between words and tunes is not completely reciprocal, however, because recognition of words seems to be less affected by the other component (i.e., musical) of the song than recognition of tunes, at least in the case of these particular materials, suggesting that words can be to a certain degree independently accessible. Even if intuitively tunes seem to be spontaneously recalled when retrieving the text of a song, the results indicate that it is probably different in a recognition task, especially after only one previous hearing. However, it might be possible to render more salient the melodic component in a recognition task under adequate experimental conditions. By using easier tunes to remember, or by asking the subjects to pay attention to the melodic part, it may be possible to trigger a more equitable use of both memory codes.

In summary, the major finding of the present investigation provides evidence for the role of the left as well as the right temporal lobes in memory for songs, suggesting that songs can be encoded in different ways. In more general terms, we conclude that there is a partial dissociation between hemispheric function and the use of different memory codes. The verbal code is consistently related to left temporal lobe structures, whereas the melodic code may depend on either or both temporal lobe mechanisms, depending on the type of encoding involved.

References

Bartholomeus, B. (1974). Effects of task requirements on ear superiority for sung speech. *Cortex, 10,* 215–223.

Borchgrevink, H. M. (1980). Cerebral lateralization of speech and singing after intracarotid amytal injection. In M. T. Sarno & O. Hook (Eds.), *Aphasia. Assessment and treatment* (pp. 186–191). Stockholm: Almqvist & Wiksell.

Bower, G. H. (1972). Mental imagery and associative learning. In L. Gregg (Ed.), *Cognition in learning and memory* (pp. 51–87). New York: Wiley.

Crowder, R. G., Serafine, M. L., & Repp, B. (1990). Physical interaction and association by contiguity in memory for the words and melodies of songs. *Memory & Cognition, 18,* 469–476.

Deutsch, D. (1972). Tones and numbers: Specificity of interference in short-term memory. *Science, 168,* 1604–1605.

Gardner, H., Silverman, J., Denes, G., Semenza, C., & Rosensteil, A. K. (1977). Sensitivity to musical denotation and connotation in organic patients. *Cortex, 13,* 242–256.

Geiselman, R. E., & Bjork, R. A. (1980). Primary versus secondary rehearsal in imagined voices: Differential effects on recognition. *Cognitive Psychology, 12,* 188–205.

Geiselman, R. E., & Glenny, J. (1977). Effects of imagining speakers' voices on the retention of words presented visually. *Memory & Cognition, 5,* 499–504.

Gordon, H. W., & Bogen, J. E. (1974). Hemispheric lateralization of singing after intracarotid sodium amylobarbitone. *Journal of Neurology, Neurosurgery, and Psychiatry, 37,* 727–738.

Grossman, M., Shapiro, B. E., & Gardner, H. (1981). Dissociable musical processing strategies after localized brain damage. *Neuropsychologia, 19,* 425–433.

Jones-Gotman, M. (1987). Commentary: Psychological evaluation—testing hippocampal function. In J. Engel (Ed.), *Surgical treatment of the epilepsies* (pp. 203–211). New York: Raven Press.

Jones-Gotman, M., & Milner, B. (1978). Right temporal-lobe contribution to image-mediated verbal learning. *Neuropsychologia, 16,* 61–71.

Meyer, V., & Yates, A. J. (1955). Intellectual changes following temporal lobectomy for psychomotor epilepsy. *Journal of Neurology, Neurosurgery, & Psychiatry, 181,* 44–52.

Milner, B. (1958). Psychological defects produced by temporal-lobe excision. *Research Publications of the Association for Research in Nervous and Mental Disease, 36,* 244–257.

Milner, B. (1962). Laterality effects in audition. In V. B. Mountcastle (Ed.), *Interhemispheric relations and cerebral dominance* (pp. 177–195). Baltimore: Johns Hopkins University.

Milner, B. (1967). Brain mechanisms suggested by studies of the temporal lobes. In F. C. Darley (Ed.), *Brain mechanisms underlying speech and language* (pp. 122–145). New York: Grune and Stratton.

Milner, B. (1975). Psychological aspects of focal epilepsy and its neurosurgical management. In D. P. Purpura, J. K. Penry, & R. D. Walters (Eds.), *Advances of neurology, Vol. 8* (pp. 299–321). New York: Raven Press.

Milner, B., Kimura, D., & Taylor, L. B. (1965). *Nonverbal auditory learning after frontal or temporal lobectomy in man.* Paper presented at the Eastern Psychological Association annual meeting, Atlantic City, NJ.

Paivio, A. (1969). Mental imagery in associative learning and memory. *Psychological Review, 76,* 241–263.

Paivio, A. (1989). Modalities of imagery and memory. In A. F. Bennett & K. M. McConkey (Eds.), *Cognition in individual and social contexts* (pp. 409–418). New York: Elsevier Science.

Paivio, A., & Csapo, K. (1973). Picture superiority in free-recall: imagery or dual-encoding? *Cognitive Psychology, 5,* 176–206.

Rasmussen, T., & Milner, B. (1977). The role of early left-brain injury in determining lateralization of cerebral speech functions. *Annals of the New York Academy of Sciences, 299,* 355–369.

Samson, S., & Zatorre, R. J. (1988). Melodic and harmonic discrimination following unilateral cerebral excision. *Brain & Cognition, 7,* 348–360.

Serafine, M. L., Crowder, R. G., & Repp, B. H. (1984). Integration of melody and text in memory for songs. *Cognition, 16,* 285–303.

Serafine, M. L., Davidson, J., Crowder, R. G., & Repp, B. H. (1986). On the nature of melody-text integration in memory. *Journal of Memory and Language, 25,* 123–135.

Shankweiler, D. (1966). *Defects in recognition and reproduction of familiar tunes after temporal lobectomy.* Paper presented at the annual meeting of the Eastern Psychological Association, New York.

Shapiro, B. E., Grossman, M., & Gardner, H. (1981). Selective musical processing deficits in brain damaged populations. *Neuropsychologia, 19,* 161–169.

Wada, J., & Rasmussen, T. (1960). Intracarotid injection of sodium Amytal for the lateralization of speech dominance: experimental and clinical observations. *Journal of Neurosurgery, 17,* 266–282.

Wechsler, D. A. (1945). A standardized memory scale for clinical use. *Journal of Psychology, 19,* 87–95.

Wechsler, D. A. (1981). *Wechsler Adult Intelligence Scale-Revised.* New York: The Psychological Corporation.

Whitehouse, P. J. (1981). Imagery and verbal encoding in left and right hemisphere damaged patients. *Brain and Language, 14,* 315–332.

Zatorre, R. J. (1984). Musical perception and cerebral function: A critical review. *Music Perception, 2,* 196–221.

Zatorre, R. J. (1985). Discrimination and recognition of melodies after unilateral cerebral excisions. *Neuropsychologia, 23,* 31–41.

Zatorre, R. J. (1989). Perceptual asymmetry on the dichotic fused words test and cerebral speech lateralization determined by the carotid sodium Amytal test. *Neuropsychologia, 27,* 1207–1219.

Zatorre, R. J., & Samson, S. (1991). Role of human right temporal lobe in auditory short-term retention of pitch information. *Journal of Clinical and Experimental Neuropsychology, 13,* 67–68.

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