Brain (2000), **123,** 1926–1938

Patterns of music agnosia associated with middle cerebral artery infarcts

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Summary

The objective of the study is to evaluate if the rupture of an aneurysm located on the middle cerebral artery (MCA) results in disorders of music recognition. To this aim, 20 patients having undergone brain surgery for the clipping of a unilateral left (LBS), right (RBS) or bilateral (BBS) aneurysm(s) of the MCA and 20 neurologically intact control subjects (NC) were evaluated with a series of tests assessing most of the abilities involved in music recognition. In general, the study shows that a ruptured aneurysm on the MCA that is repaired by brain surgery is very likely to produce deficits in the auditory processing of music. The incidence of such a deficit was not only very high but also selective. The results show that the LBS group was more impaired than the NC group in all three tasks involving musical long-term memory. The study also uncovered two new cases of apperceptive agnosia for music. These two patients (N.R. and R.C.) were diagnosed as such because both exhibit a clear deficit in each of the three music memory tasks and both are impaired in all discrimination tests involving musical perception. Interestingly, the lesions overlap in the right superior temporal lobe and in the right insula, making the two new cases very similar to an earlier case report. Altogether, the results are also consistent with the view that apperceptive agnosia results from damage to right hemispheric structures while associative agnosia results from damage to the left hemisphere.

Keywords: auditory agnosia; amusia; auditory organization; music; hemispheric differences

Abbreviations: ANOVA = analysis of variance; BBS = bilateral brain surgery; LBS = left brain surgery; MCA = middle cerebral artery; NC = normal control; RBS = right brain surgery

Introduction

Recognition of familiar music is immediate and easy for every human being. Despite its apparent effortlessness, music recognition is a complex procedure that implies multiple processing components. Damage to one or many of these components produces music agnosia. Such a neurologically based deficit is characterized by the inability to recognize music in the absence of sensory, intellectual, verbal and mnesic impairments (Peretz, 1996).

As Peretz has argued elsewhere (Peretz, 1993), music agnosias may have either a perceptual melodic basis or a memory basis. Music recognition may be conceptualized as a two-stage process as illustrated in Fig. 1. According to this model, music agnosia may be due to a failure to encode melodic information properly, defined by sequential variations of pitch. Such a perceptual melodic impairment would prevent the familiar musical passage from making contact with its stored representation. The long-term memory representations may, however, be spared by the brain damage although the traces are no longer accessible by auditory input. Such a recognition deficit due to a perceptual defect falls into the class of apperceptive agnosias. The other form of music agnosia results from an isolated loss of memories for music, i.e. the breakdown can spare most perceptual abilities but interfere with the recognition process by damaging the network of the long-term memory representations of music. This form of disorder is known as associative agnosia.

According to this model, the patient H.V. studied by Griffiths and colleagues (Griffiths *et al.*, 1997) would suffer from an apperceptive form of music agnosia. Actually, H.V. has been shown to suffer from a perceptual defect and to be able to sing from memory. Conversely, Peretz has described a case of associative agnosia for music (Peretz, 1996). This case, C.N., who had recovered most perceptual skills, is still unable to sing from memory, to name a familiar tune, to

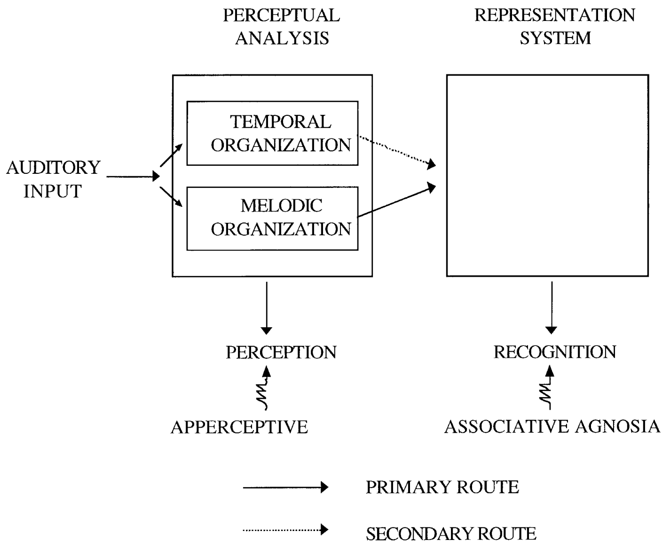

Fig. 1 Peretz's model of music agnosias (Peretz, 1993).

judge its familiarity or to memorize familiar and novel music. Since H.V. suffered from an unilateral lesion in the right hemisphere and C.N. suffered from bilateral damage, one can propose tentatively that apperceptive agnosia is related to a right-sided lesion and associative agnosia is associated with bilateral infarcts.

The two patients, H.V. and C.N., differ not only in the nature of their music agnosic disorder but also in neurological history. H.V. suffered from a unilateral posterior infarction involving the posterior superior temporal gyrus and the inferior parietal and anterolateral occipital lobes in the right hemisphere. C.N. had more anterior lesions in both superior temporal gyri resulting from repeated surgery for the repair of an aneurysm located on the middle cerebral artery (MCA). Interestingly, C.N.'s neurological history is identical to that of two further cases of music agnosia, G.L. and I.R., who were discovered independently and whose selection was symptom based (Peretz *et al.*, 1994, 1997). All three underwent repeated brain surgery for the clipping of aneurysms located in mirror position on each MCA. This particular brain condition associated with surgical intervention might result in music agnosia. One goal of the present study was to test these neural correlates of music agnosia.

The other major objective of the present study was to assess the idea that apperceptive agnosia is more likely to arise from a right-sided infarct of the superior temporal gyrus because it would compromise the melodic route. As seen in Fig. 1, there are two main processing routes that are assumed to lead to memory representations: the melodic and temporal routes. However, the melodic route is conceived as having primacy for accessing stored music representations. In effect, it is relatively well established that the essential processing components of the melodic route lie in the right superior temporal gyrus (Peretz, 1990; Zatorre *et al.*, 1994; Liégeois-Chauvel *et al.*, 1998) with possible connections with the right frontal areas (Zatorre and Samson, 1991; Zatorre *et al.*, 1994). Moreover, this right-sided melodic route can be interrupted without disturbing the temporal route (Peretz, 1990; Peretz and Kolinsky, 1993; Liégeois-Chauvel *et al.*, 1998). Finally, this isolable melodic route is conceived as primary because neurologically intact subjects have been shown to use melodic features more effectively than temporal patterns to recognize familiar musical selections (White, 1960; Hébert and Peretz, 1997). Therefore, there are grounds to consider apperceptive agnosia as resulting from a right-sided interruption of the melodic route.

The neural correlates of the memory component of the music recognition system are more elusive. Learning and long-term retention of novel melodies seem to rely more on the integrity of the right than the left hemisphere (Samson and Zatorre, 1991, 1992; Plenger *et al.*, 1996; but see Zatorre, 1985; Peretz, 1990, for bilateral involvement). However, recognition of highly familiar music has been shown to depend more on the left hemisphere (Platel *et al.*, 1997). To avoid the confusion created by variable levels of prior familiarity with the musical material, both highly familiar and totally unfamiliar musical excerpts will be tested here for memory recognition. Yet, no clear prediction as to the side(s) of the infarct(s) that would lead to selective impairments of memory recognition for music (i.e. associative agnosia) will be formulated at this stage.

In the present study, in order to test the neural underpinning of music agnosia, the musical agnosic pattern associated with brain surgery for the clipping of an aneurysm located on the left, the right or both MCAs was investigated in 20 patients and their neurologically intact matched controls. The participants were presented with the same series of musical tests as those used in earlier studies with music agnosics (Peretz *et al.*, 1994, 1997) and with patients with unilateral temporal excisions for the relief of epilepsy (Liégeois-Chauvel *et al.*, 1998). These tests have been designed to test the major processing components that are known to be involved in music recognition. These include several discrimination tasks in which pitch contour, pitch interval and scale steps are assessed on the melodic dimension, and rhythm and regularity on the temporal dimension. Several music recognition tasks are included as well to assess the memory component of the music recognition system. These tests cover memory recognition of novel musical excerpts as well as recognition and identification of well-known musical selections. The results of the patients obtained across these multiple tests should provide us with a good picture of the relationship between surgery on the MCA and the ensuing musical condition.

Methods

Subjects

Twenty patients who had undergone brain surgery for the clipping of a ruptured aneurysm located on the temporal

Table 1 *Characteristics of subjects*

Group	Sex M	Sex F	Average age (years)	Average education (years)	IQ (SE)	MQ (SE)
LBS	1	6	49	10	97 (1, 54)	105 (2, 11)
RBS	1	9	47	13	108 (1, 41)	111 (0, 92)
BBS	1	2	51	12	99 (1, 64)	102 (2, 12)
NC	3	17	48	13	–	–

SE = standard error.

Fig. 2 Example of an initial melody (**A**), and its scale-violated (**B**), contour-violated (**C**), interval-violated (**D**) and rhythmic (**E**) transformation. **F** represents the entire two-phrase sequence (of which the second phrase corresponds to **A**) used in the metric task. The asterisk indicates the critical note.

region of the right ($n = 10$), left ($n = 7$) or both ($n = 3$) MCAs participated in the present study. Informed consent was obtained from all of them and the study was approved by the Ethical Committee of the Institut Universitaire de Gériatrie de Montréal. CT scans were carried out from 1 day to 63 months post-surgery (mean: 15 months) with 10 mm axial section. Not all patients showed evidence of brain infarct on CT scan examination (MRI scans could not be obtained due to the use of metallic clips). However, they all underwent the same brain surgery which was performed by the same neurosurgeon (author M.B.). The patients were tested, on average, 30 months (range: 6 months to 7 years) postoperatively. The majority of patients (15) were evaluated >1 year postoperatively. A summary of the patients' characteristics is presented in Table 1 along with the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981) scores and the Wechsler Memory scale (Wechsler, 1974) scores. The right (RBS) and left (LBS) brain surgery patient groups were not found to differ in IQ [$F(2,17) = 2.12$, NS] or in MQ (memory quotient) ($F < 1$). Two LBS patients had some aphasic problems but their speech comprehension was preserved.

There were 20 neurologically intact controls (NC) who were selected to match the brain-damaged patients in age, sex, handedness, education and musical background. In Table 1, the sex distribution, average age and years of education are summarized for each group. A history of alcohol abuse, psychiatric disorder or other neurological illness was grounds for exclusion. Only people raised in the French culture of Quebec were selected in order to have a homogeneous group with respect to musical knowledge. Most participants were right-handed, with the exception of two LBS patients (and their respective matched normal controls), one of whom was left-handed and the other ambidextrous. None of the subjects currently was or had recently been involved with music. Only 10% of the subjects in each group could be considered as having had some musical experience, in that they practised an instrument during childhood.

Material and procedures

Eight behavioural tests involving melodies that obeyed the rules of the Western tonal system were employed. Six of them use the same pool of 30 *novel* melodies and are used in what we refer to as the musical battery. Two further tests, the familiarity decision test and the identification test, employ melodies that are expected to be familiar to anyone from the Quebec Francophone culture.

Musical battery

The musical battery (which is fully described in Liégeois-Chauvel *et al.*, 1998), is composed of six tests, three of which deal with pitch variation discrimination, two with temporal variation discrimination and one with memory.

In the pitch organization conditions, three types of manipulation were applied to the same tone in 15 sequences. One manipulation consisted of creating a scale-violated alternative melody by modifying the pitch to bring it out of scale (within the same semi-tone distance across stimuli), in keeping with the original contour. This change is particularly salient because the changed pitch sounds out of tune (see melody B in Fig. 2). The second manipulation consisted of creating a contour-violated alternative melody by modifying the critical pitch so that it changed the pitch direction of the surrounding intervals while maintaining the original key (see melody C in Fig. 2). The third manipulation consisted of creating a contour-preserved or interval-violated alternative melody of the contour-violated and scale-violated melodies by modifying the same critical pitch to the same extent (in terms of semi-tone distance), while maintaining the original contour and scale (see melody D in Fig. 2). Average pitch interval changes were made equivalent across the three conditions.

Three sets of stimuli, each consisting of two practice trials and 30 experimental trials, were constructed with these melodies. Each trial consisted of a warning signal and a target melody followed by a comparison melody after a 2-s silent interval. The duration of the inter-trial interval was 5 s. A first set, which was prepared for the scale-violated condition, was constructed so that 15 trials were made of identical melodies and 15 trials of different scale-violated melodies. The second and third set, which were designed for the contour-violated and the interval-violated condition, respectively, were similar to the scale-violated condition set in that they kept the same target melodies; the only modification was that each comparison melody was replaced by its contour-violated alternative or by its preserved-contour alternative. Melody pairs were presented in each set in a random order. These three conditions will be referred to as the scale, contour and interval conditions. Subjects were required to perform a 'same–different' classification task. They had to judge, on each trial, whether the target and the comparison sequence were the same or not.

The temporal organization tasks involved two tests, one rhythmic and one metric test. For the rhythmic test, the stimuli were the same as those used in the pitch organization tests. To create different comparison patterns, a change in the duration values of two adjacent tones was applied to keep the meter and the total number of sounds identical. The serial positions of these changes varied across patterns (see melody E in Fig. 2). Thus, the only cue available for discrimination was the rhythmic pattern. A set of two practice and 30 experimental trials was constructed with the temporal patterns. The task also required a 'same–different' classification. For the metric test, two-phrase sequences instead of the one-phrase sequences used in the previous tests were recorded in a random order with a 5-s inter-trial interval. Half of these sequences were written in a double meter and half in a triple meter. Subjects were informed that they would be hearing waltzes and marches which they had to discriminate along this dimension (see melody F in Fig. 2). They were encouraged to tap along with what they perceived to be the underlying beat of each sequence. There were four practice trials preceding 30 experimental trials.

The last test of the musical battery was a memory recognition test. From the initial set of 30 single-phrase melodies, 15 were selected for the recognition part of this study. Each had been presented at least five times in the same format. In addition to these 'old' melodies, a set of 15 recognition foils was prepared. The 'new' melodies were constructed along the same principles, but differed from the 'old' ones in their exact temporal and pitch pattern. The 30 sequences were then recorded in a random order with a 5-s silent interval in between. The subjects were requested to respond 'yes' if they recognized a melody as having been presented earlier during the session and to respond 'no' if otherwise. This last test was as an incidental memory test since the subjects were not informed in advance that their memorization of the material would be tested later.

Familiarity decision test

The melodic part of the beginnings of 40 folk songs selected from a list of pieces well known to Quebec Francophones (Peretz *et al*., 1995) were mixed, in a random order, with 40 melodies from the same repertoire of folk songs but which were unfamiliar because they are no longer sung or played. The familiar melodies had a mean rating of 4.5 (following our norms, 1 = unfamiliar and 5 = familiar). The duration of melodies, which was on average 8.5 s, was equivalent in familiar and unfamiliar excerpts. There was a 5-s silent interval between melodies. The subjects had to judge, on each trial, if the melody was familiar or unfamiliar. Prior to the task, two practice trials were presented and feedback on the response was only provided for the two practice trials.

The identification test

Fifty-two melodic intros of folk songs were chosen from the same pool of familiar musical excerpts (Peretz *et al*., 1995). They were associated with a mean familiarity rating of 4.6 and lasted 9 s, on average. The melodies were separated by a 5-s silent interval. Each melody presented was associated with a choice of four written titles, one of which was the correct title. The foils were of the same genre (e.g. all titles would be Christmas songs). The subjects were first invited to give the title of the melody they had heard; in the case of failure, they were presented with the four written choices from which they had to choose. No feedback on the accuracy of the choice was provided.

All stimuli were generated on an IBM-AT compatible microcomputer controlling a Yamaha TX-81Z synthesizer. The voice was the approximation of a piano sound. The analogue output was recorded on a digital DAT Sony recorder which was also used to play melodies to the subjects. The subjects were tested individually in two sessions of ~2 h each with as many pauses in between conditions as requested. They listened to the pre-recorded tapes via a speaker placed on a table in front of them. The intensity level was adjusted to a comfortable level for each subject. Subjects were presented, successively, with the pitch organization conditions (scale-violated, contour-violated and interval-violated), the temporal organization tasks (rhythmic task, metric task), the memory recognition test of unfamiliar melodies, the recognition test of familiar melodies and the music title identification test. The musical battery was always presented in the same session.

Results

Individual scores were transformed into hits and false alarms, except for the identification test where this was not appropriate, and examined by analyses of variance (ANOVAs). The scores obtained on different tests were grouped in the same analysis when the tests were assessing abilities in comparable experimental conditions. For example,

Table 2 *Individual hits minus false alarms rate in each test and percentage of correct responses in the identification test for each patient (cut-off points, mean percentage and corresponding standard deviation, for normal controls are given for each test)*

	Pitch organization			Temporal organization		Memory recognition	Familiarity decision	Global identification
	Scale	Contour	Interval	Rhythmic	Metric			
LBS1	67	20*	47	47	73	40	43*	65*
LBS2	93	47	67	80	40	80	98	100
LBS3	47	40*	7*	73	60	7*	88	81
LBS4	73	80	73	33*	7*	27*	70	67*
LBS5	87	87	73	67	87	60	75	81
LBS6	73	53	53	47	67	33	83	79
LBS7	80	80	47	67	53	40	70	96
RBS8	100	80	87	80	87	87	93	100
RBS9	27*	40*	33	60	67	20*	78	81
RBS10	60	80	53	100	40	60	83	96
RBS11	47	27*	20*	40	73	47	80	92
RBS12	53	0*	13*	87	33	67	85	87
RBS13	93	87	87	93	87	80	100	100
RBS14	47	73	60	67	27	67	85	100
RBS15	93	93	93	100	87	87	78	100
RBS16†	0*	–7*	–7*	0*	33	27*	63*	75*
RBS17	67	67	53	80	73	60	90	98
BBS18	53	20*	33	53	53	33	75	98
BBS19†	13*	20*	13*	40	13*	27*	55*	69*
BBS20	33*	40*	20*	73	53	–7*	75	71*
Normal controls								
cut-off point	47	47	33	40	20	33	65	79
mean	81	74	71	80	58	72	91	96
SD	15	14	19	16	20	17	7	6

SD = standard deviation. *Scores under the cut-off point. †Agnosic patients.

both the memory recognition test and the familiarity decision test involve a binary decision that requires explicit memory for melodies. Accordingly, the test scores were examined together in the same ANOVA. Non-parametric tests were performed when the results were not homogeneous. Because there were few subjects in the BBS group, the results for this group were not included in the statistical analyses but they are presented in the figures and tables. All individual scores were examined (fully presented in Table 2) and classified with respect to the lowest performance obtained by the NC which was considered as the cut-off point below which the scores can be regarded as indicating a genuine deficit. Note, however, that this criterion is conservative since some scores above the cut-off points could reflect deficient systems that were excellent premorbidly. The results will be presented below according to the processing component that is assessed by the test(s), starting with the diagnostic tests for music agnosia, followed by the more perceptual tests and ending with lesion localization.

Recognition tests

The old–new recognition tests

The responses were considered as hits when the subjects responded 'old' to studied melodies and 'familiar' to well-known melodies, and as false alarms when responding 'old' to non-studied or unfamiliar melodies. The mean percentages of hits and false alarms obtained by each group in the memory recognition test and the familiarity decision test are presented for each group in Fig. 3. Since the two tests mainly differ in terms of pre-experimental familiarity with the melodies, they will be treated in a single ANOVA. Hits and false alarms were submitted to separate ANOVAs, with the test material (familiar and unfamiliar melodies) taken as the within-subjects factor and the three groups (NC, LBS and RBS) as the between-subjects factor. On hits, the analysis yielded an effect of test material [$F(1,34) = 8.41$, $P < 0.01$)] but no effect of group ($F < 1$) or interaction between the two factors ($F < 1$). Subjects performed generally better in the familiarity decision test than in the memory recognition test. False alarm rates exhibit a slightly different pattern, as supported by the presence of an interaction between test material and group [$F(2,34) = 3.26$, $P < 0.05$]. The LBS group was found to produce more false alarms than the NC group ($P < 0.001$) and the RBS group ($P < 0.06$) in the memory recognition test (by way of Tukey *a posteriori* tests). In the familiarity decision test, LBS patients also made more false alarms than the NC group ($P < 0.02$) but not significantly more than the RBS patients. Thus, all subjects performed well on these melody recognition tests when hit rates were

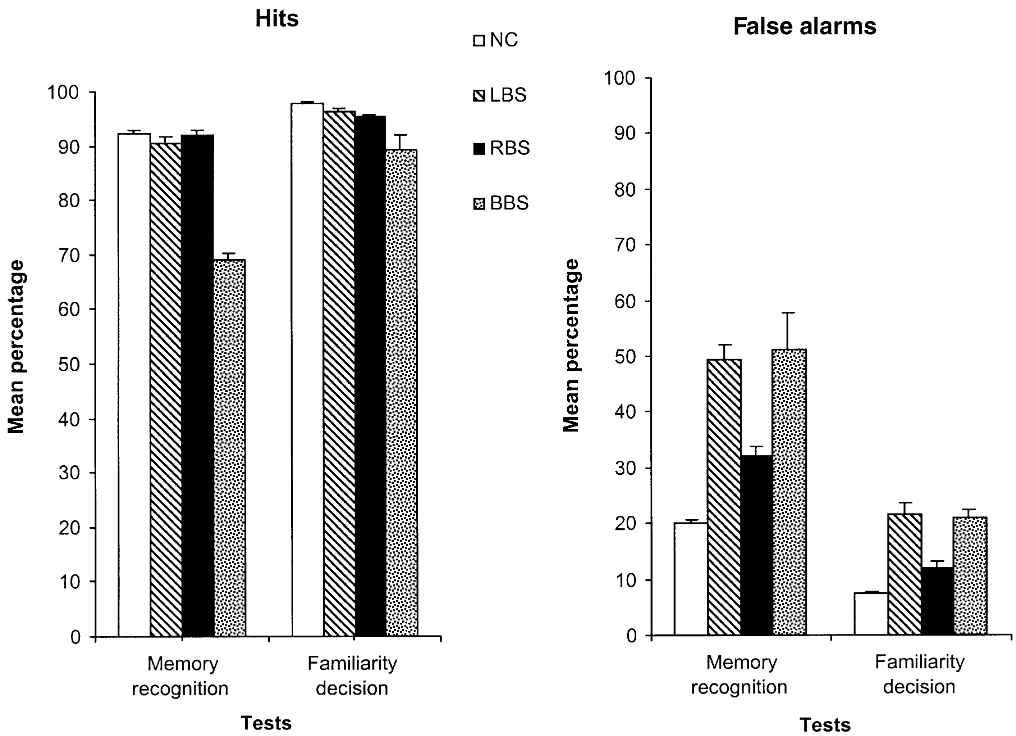

Fig. 3 Mean percentages of hits and false alarms obtained, in each group, for the two old–new recognition tests. The error bar represents the standard error.

examined. However, patients with LBS tend to produce more false recognition than the other groups. This impairment is, however, not as serious as the deficit exhibited by BBS patients (see Fig. 3 and Table 2 for the individual scores) who performed poorly on the memory recognition test.

The identification test

The mean percentages of correct responses for each group obtained globally by adding the correct naming responses to the correct title choices are presented, along with the naming responses, in Fig. 4. The two scores were analysed separately with group as the between-subjects factor. On both the global scores and the correct naming scores, a group effect was obtained, with $F(2,34) = 7.37$ and 4.20, both $P < 0.05$, respectively. Tukey comparisons reveal that this group effect was due to the lower performance of the LBS group ($P < 0.02$ compared with the NC group). Note that, on this identification test, the LBS patients are as impaired as the BBS patients (see also Table 2 for individual data). Thus, left-brain surgery seems to interfere with the ability to recognize familiar melodies reliably.

The results obtained across the three recognition tests—the memory recognition test of studied novel melodies, the familiarity decision test and the identification test—allow the classification of patients as exhibiting agnosic symptoms or not. Patients exhibiting a deficit in any of the recognition tests are qualified as music agnosic. As expected from the previous analyses, there are more agnosic patients after LBS (three out of seven) and BBS (two out of three) than after RBS (two out of 10; see Table 2). However, if we use more stringent criteria, as are currently applied to single case studies, and require evidence of a deficit in each of the music recognition tests, since all of them aim at assessing the same processing component (the memory component in Fig. 1), then only two patients can be qualified as showing clear evidence of music agnosia. These two patients are RBS16 and BBS19 (see Table 2), hence suggesting a contribution of the right-hemispheric structures. The origin of the agnosic problem is expected to differ for LBS (and BBS) and RBS patients, with the latter pertaining more to the apperceptive type of agnosia and the former to the associative type. The scores obtained in the discrimination tests, examined next, will allow the classification of the patients according to each type of agnosia.

Perceptual tests

In the discrimination tests, a ‘different’ response given to a ‘different’ trial was considered as a hit, whereas a ‘different’ response given to a ‘same’ trial was considered as a false alarm. Since the false alarm rates were found to be very similar in all patient groups, we used the number of hits minus the number of false alarms as a unique discrimination score in both statistical analyses and in the figures and tables to simplify data description.

In the pitch organization tests, the hits minus false alarms scores were submitted to an ANOVA, with the three

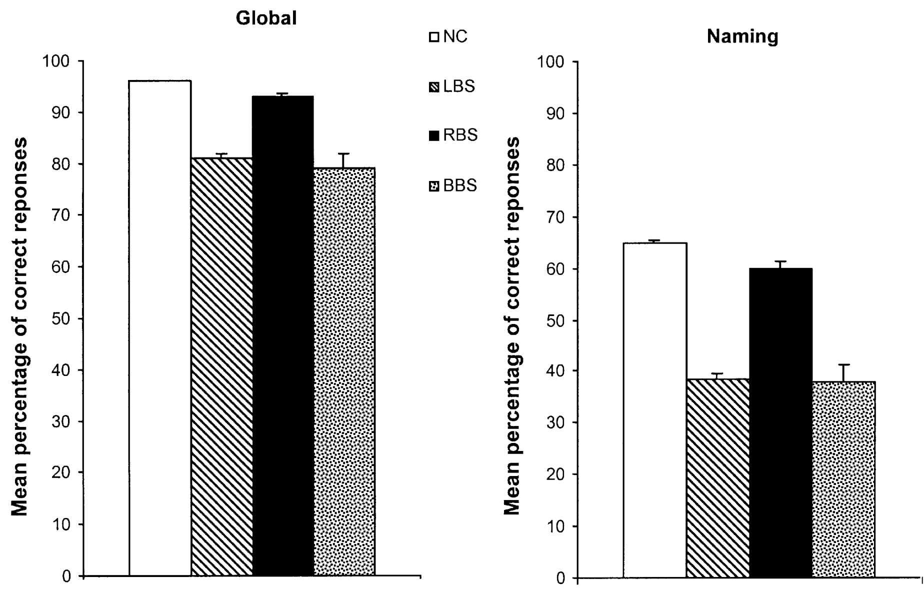

Fig. 4 Mean percentages of correct responses obtained, in each group, for the identification test. The global score includes both correct naming and correct title selection. The error bar represents the standard error.

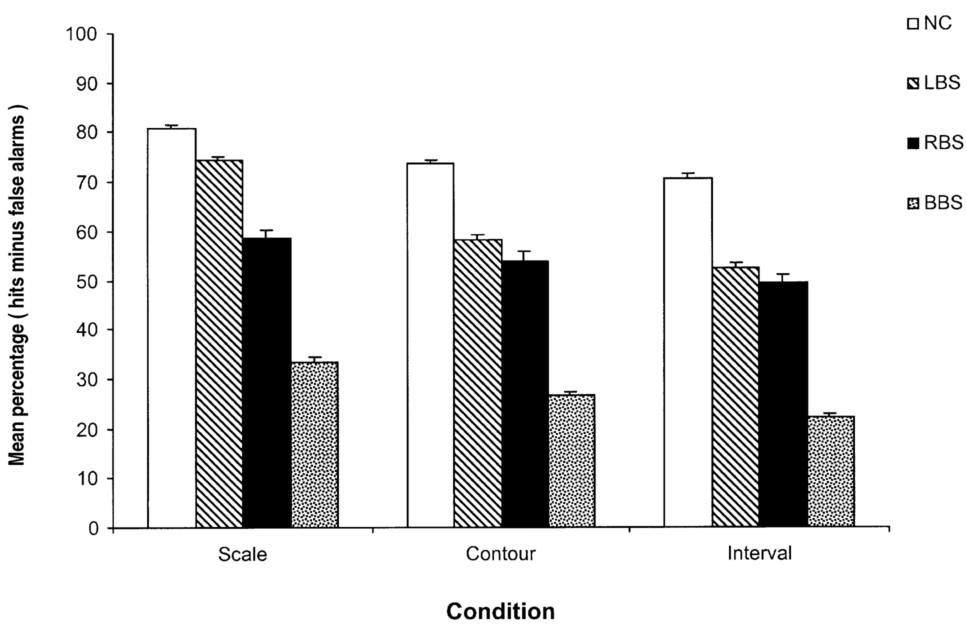

Fig. 5 Mean percentages of hits minus false alarms obtained, in each group, for the three pitch organization tests. The error bar represents the standard error.

conditions (scale, contour and interval) as the within-subjects factor and the three groups (NC, LBS and RBS) as the between-subjects factor. As can be seen in Fig. 5, the RBS group appears impaired in all conditions while the LBS group seems to experience fewer difficulties with the scale condition. However, this different pattern lacks robustness since no significant interaction between group and condition was obtained ($F < 1$, NS). The patients were impaired across conditions, irrespective of the melodic condition considered and the side of the surgery [$F(2,34) = 3.57$, $P < 004$, for the group effect]. Non-parametric statistical analyses of the data yielded essentially the same results

Inspection of individual data (in Table 2) reveals a series of interesting facts. First, out of the nine patients exhibiting a deficit in the contour condition, six were clearly, and three mildly, impaired in the interval test. This systematic association between the deficits observed in contour and interval conditions is consistent with the anchorage role conferred on the contour for encoding intervals (Peretz, 1990). Secondly, three patients (RBS16, BBS19 and BBS20)

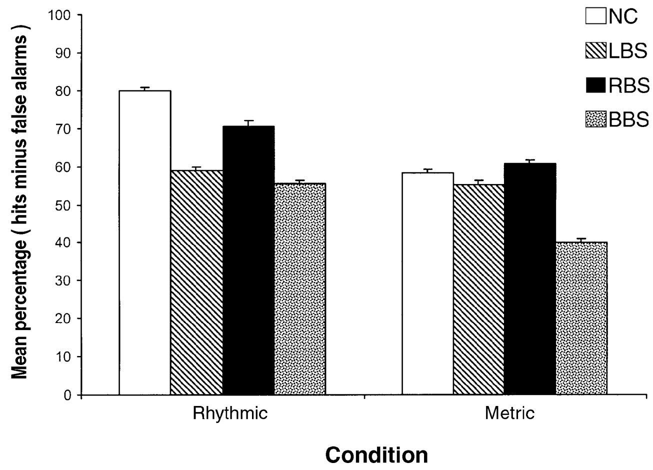

Fig. 6 Mean percentages of hits minus false alarms obtained, in each group, for the two temporal organization tests. The error bar represents the standard error.

demonstrated a deficit in all three pitch tests. These three patients are expected to have agnosic disorders since there is converging evidence that their melodic route does not function properly, hence interfering with the most essential access to music memory (see the model in Fig. 1). The latter prediction is consistent with the data. As can be seen in Table 2, all three patients show signs of recognition failures.

For the temporal organization tests, the mean percentages of hits minus false alarm scores are displayed in Fig. 6. A correct response to a 'waltz' was considered here as a hit and a 'waltz' response given to a march was considered as a false alarm. Performance on the two tasks was analysed separately because task parameters were different, the metre task requiring an on-line judgement for each sequence and the rhythm task requiring a 'same–different' classification for two such sequences. No significant group effect was obtained in either task [with $F(2,34) = 2.69$ and $F < 1$, for the rhythmic and metric test, respectively].

The individual scores are more informative than group data, as was the case for the pitch organization conditions. As can be seen in Table 2, performance is highly variable in the metric task and is associated with a very low cut-off score. Consequently, results in this particular test are difficult to interpret. This is not the case for the rhythmic test on which the large majority of patients perform within the normal range. Only two out of the 20 patients show a deficit in rhythm discrimination. The latter result suggests that either rhythmic deficits are less frequent than melodic ones or that the brain surgery under study is less detrimental to rhythm processing than other types of brain injury, such as excision of brain tissue in the temporal lobe for the relief of epilepsy which will be examined next.

Incidence of musical disorders

As pointed out previously, brain surgery for the clipping of an aneurysm located on the MCA was thought to be instrumental in producing music perception and recognition disorders. In order to assess the validity of such a claim, we compared the frequency of occurrence of a deficit in the present study with a previous study of ours where the same musical tests were administered to another population of patients. The latter sample was made up of 62 patients who underwent unilateral excision of brain tissue in the temporal lobe for the relief of epilepsy. The percentages of patients exhibiting a deficit (defined as a score below the lowest score of NC subjects) in each test that was used in both studies are presented in Table 3.

Although the present study includes fewer patients than the previous one, the comparison is very instructive. In effect, the incidence of pathological performance, defined as a score falling outside the normal distribution, is much higher in the present sample than in the epileptic population (Liégeois-Chauvel *et al.*, 1998). This may, however, not be related to the type of brain surgery. The functional brain organization of the two populations may well differ preoperatively. The premorbid brains of the individuals tested in the present study were, in all likelihood, similar to those of the normal controls. This is probably not the case for the epileptic brain which often has been ill-functioning since early childhood and, hence, may have undergone some functional reorganization. However, we cannot conclude that surgical repair of a ruptured aneurysm on the MCA is a perfect road to music agnosia. Any vascular infarct of the same territories may well lead to a similar high rate of musical deficits.

It is, however, remarkable to note that bilateral intervention appears more disturbing than unilateral intervention. It does not seem to be a trivial mass effect, whereby the more damaged tissue there is the more likely it is that a deficit will be observed. Bilateral intervention seems to spare temporal organization processes while severely compromising both melodic organization processes and memory.

Lesion localization

Out of the 20 patients' postoperative brain CT scans, only 15 could be examined for localization of the infarction. Two scans were not available, and the extent of infarction could not be visualized in three scans because they were taken in the acute ischaemic phase. Moreover, among the 15 scans, five contained artefacts in the regions of interest due to the presence of metallic clips on the MCA, preventing us from examining the temporal lobe structures properly. Two neuroradiologists (authors I.R. and C.B.) reviewed the cases according to the following structures: the anterior, middle and posterior portion of the superior temporal gyrus, the middle temporal gyrus, the temporal pole, the inferior parietal lobe and the frontal operculum. A summary is presented in Table 4.

As indicated in Table 4 and as expected, most patients show infarcts involving structures of the superior temporal gyrus, except cases LBS3 and RBS9. These two cases do not undermine the idea that the critical areas for music

Table 3 *Percentages (and numbers) of patients with a deficit in music tasks*

	Scale	Contour	Interval	Rhythm	Meter	Memory recognition
Aneurysm						
Left (7)	0	29	14	14	14	29
Right (10)	20	40	30	10	0	20
Bilateral (3)	67	100	67	0	33	67
Total (20)	20	45	30	10	10	30
Epilepsy						
Left (27)	0	11	11	0	11	0
Right (35)	11	6	9	11	31	14
Total (62)	6	8	10	7	23	8

Aneurysm = temporal surgery for the repair of an aneurysm (present study); Epilepsy = temporal surgery for excision of epileptic tissue (Liégeois-Chauvel *et al*., 1998).

Table 4 *Summary of CT scan low-density areas*

	Heschl	STGa	STGm	STGp	MTG	PT	IPL	FO	Insula	Frontal
LBS1 (lefthanded)	+	+	+							
LBS2	–	–	–	–	–	–				
LBS3										+
LBS4	+	+	+	+	+	+	+	+	+	
LBS6				+		+	+	+	+	
LBS7 (ambidextrous)	–	–	–	–	–	–				+
RBS8						×				
RBS9									×	
RBS10	–	–	–	–	–	–				×
RBS11		×								
RBS14	×	×	×	×	×					×
RBS16**	×	×	×	×	×	×	×		×	×
RBS17		×								×
BBS18	×	×	×	×	×	×+	×		×	
BBS19**	×					×			×	

** = Agnosic patients; × = right lesion; + = left lesion; – = not assessed due to artefacts; STG = superior temporal gyrus (a = anterior; m = middle; p = posterior); MTG = middle temporal gyrus; PT = planum temporal; IPL = inferior parietal lobule; FO = frontal operculum.

processing lie in the superior temporal gyrus because the surgery involves compression of those areas and subsequent lesions often do not appear on CT scans, particularly clinical CT scans such as those obtained here which are of low resolution. Of more interest are the CT scans of the two music agnosic patients identified in the present study (RBS16 and RBS19) which do show some overlap in their lesion localization. Both have visible lesions in the right primary auditory cortex (Heschl's gyrus), the right temporal pole and the right insula. The images of the scans corresponding to these structures are presented in Fig. 7. The right temporal pole may not be critically associated with music agnosia since the only unimpaired patient (RBS8), whose performance lies in the high normal range (see Table 2) and for whom we had a readable CT scan, shows a visible lesion in that region (see Table 4). Moreover, excision of that particular region has been shown to have little impact on music discrimination and memory except for the metric test (Liégeois-Chauvel *et al*., 1998). The right primary auditory area (Heschl's gyrus) must also play a role, although damage to this area does not seem to be mandatory since the right Heschl's gyrus was spared in I.R., C.N. and G.L. Interestingly, the right insula appears as a serious candidate since it is damaged in all documented cases of music agnosia [in H.V. (Griffiths *et al*., 1997); in C.N. and G.L. (Peretz *et al*., 1994); and in I.R. (Patel *et al*., 1998), for more detailed reports and images of the respective scans].

Discussion

The results confirm the high incidence of disorders of music perception and memory that result from the surgical repair of aneurysm(s) located on the MCA. The results also emphasize the usefulness of systematically investigating patients who have sustained injuries from such brain surgery, in order to shed light on the neural correlates of the seemingly rare condition of music agnosia. Such an approach has led to the discovery of two new cases of music agnosia. It has

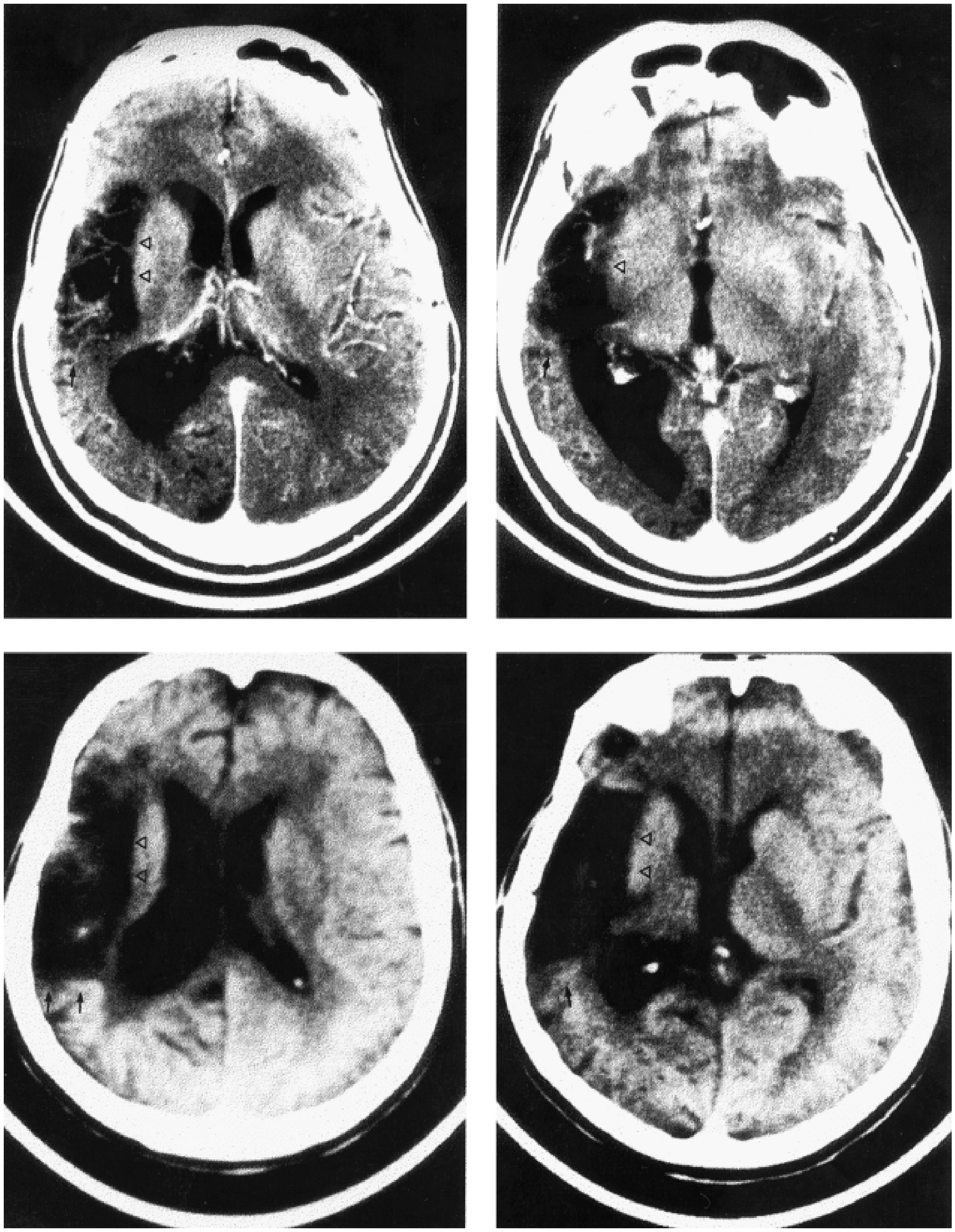

Fig. 7 Axial CT scan images of the brain of two music agnosic patients, BBS19 or R.C. (top images, without contrast injection) and RBS16 or N.R. (bottom images, with contrast injection): MCA infarct involving the insular cortex (open arrowheads) and the temporal lobe (arrow) including Heschl's gyrus. The right side of the brain is on the left of the photograph.

also led to evidence showing that the left side of the brain is better equipped for hosting long-term memory representations of music and that the right side is essential in mediating access to these stored representations.

Two clear-cut cases of music agnosia have been identified. Milder forms of music agnosia were found in five other cases, showing the chances of finding patients with music recognition disorders to be 35% (seven out of 20) in an unselected sample of patients who underwent brain surgery for the clipping of an aneurysm on the MCA. When present, the disorder consists of failure to encode the musical material properly and in poor performance on at least one of the three memory tests that were used in the study. Since the memory deficits were associated systematically with deficits in the discrimination tests, the pattern is most consistent with the observation of disorders pertaining to apperceptive agnosias. Associative agnosia, reflecting preserved perceptual abilities in the absence of recognition skills, must be rare since we did not observe any such cases here.

Of the two clear-cut cases of apperceptive agnosia

Table 5 *Performance of RBS16/N.R. and BBS 19/R.C. on neuropsychological non-musical tests*

Tests	N.R.	R.C.
Audiometry	–	Mild bilateral loss for frequencies > 3 kHz
IQ	87	105
Verbal	88	108
Performance	89	98
MQ	97	103
Lyrics recognition		
Naming	13/22	18/23
Familarity decision	20/20	18/20
Voice recognition	–	22/33
Environmental sounds recognition	–	33/45

MQ = memory quotient; – = not assessed

documented here, one (RBS16) is a 51-year-old right-handed woman, who we will refer to as N.R., who works as a hairdresser. The other (BBS19), who we will refer to as R.C., is a 44-year-old man who works as an audio-visual technician in a college. Both are musically uneducated, although the second has recently (and ironically) started to learn to play the accordion. These two cases are considered clear instances of the agnosic syndrome because they performed consistently and systematically below the normal range in all three tests that required access to music memory. Both performed poorly in the recognition of recently learned melodies, in the discrimination of familiar from unfamiliar melodies, and in identifying highly familiar melodies by naming or title recognition. All tests require normal access to an intact memory network for music; such access was obviously deficient in these two patients. Both N.R. and R.C. performed very poorly in all tests that require discrimination of musical sequences along the melodic and temporal dimension. Thus, both N.R. and R.C. must experience difficulties in encoding musical information accurately. This encoding deficiency may account for their poor recognition skills for music. However, this perceptual impairment is not general. The music agnosic disorder appears more marked for music than for other domains. For instance, both patients were able to distinguish between lyrics taken from familiar songs and familiar idiomatic expressions (this test is referred to as ‘familiarity decision’ in Table 5). They were able to provide the titles of songs for which they can no longer recognize the isolated melody when presented with the corresponding spoken lyrics. R.C. performed much better than N.R. in this task (see Table 5); it should be noted, however, that the task is particularly laborious even for neurologically intact subjects and that N.R.’s performance falls in the low normal range. However, R.C.’s auditory disorder is not music-specific either. R.C. is slightly impaired in the recognition of non-verbal patterns, such as when recognizing speakers’ voices and when invited to recognize particular categories of environmental sounds (Faïta *et al*., 1996).

The discovery of these two music agnosic patients increases our studied pool to five cases, all having the same neurological aetiology. This constitutes a relatively high hit rate, given the paucity of similar cases of music agnosia in the literature (Griffiths *et al*., 1999; Dalla Bella and Peretz, 2000). This observation in turn supports our hypothesis that brain damage incurred by the clipping of a ruptured aneurysm on the MCA is likely to lead to music agnosia and hence may serve as a good resource for studying this particular form of auditory agnosia. In this respect, it is worth mentioning that the deficit is not transient since both patients (N.R. and R.C.) were tested at least 3 years postoperatively. Note, however, that the music agnosic problem does not appear as severe as that observed in our prior bilateral cases (C.N., G.L. and I.R.) but is similar to that experienced by the unilateral case H.V. (Griffiths *et al*., 1997). Similarly to H.V., both N.R. and R.C. show damage to the right side in the brain images, evidence that a right-sided lesion appears sufficient to produce the music agnosic disorder. Images of the brain of N.R. (bottom images) and R.C. (top) are presented in Fig. 7. Unilaterality of the lesion is perhaps not warranted in the case of R.C. since he sustained brain surgery on the left side as well, for clipping a mirror aneurysm before it ruptured. Nevertheless, it is worth emphasizing that all three cases (H.V., N.R. and R.C.) of apperceptive agnosia for music have damage to similar areas in the right side of the brain. All three cases show evidence of brain lesions in the right posterior region of the superior temporal gyrus and in the right insula. These regions are, in all likelihood, critically involved in music processing for the purpose of recognition. It remains to be determined whether the insula association is accidental, and thus silent with respect to music recognition, or rather instrumental.

As seen in these two cases of apperceptive music agnosia, a right-sided lesion appears to disrupt recognition of music because of a perceptual defect and not because of a memory defect *per se*. As mentioned above, the music recognition disorder is probably due to a failure to encode musical information accurately. In this respect, the perceptual impairment would prevent the presented musical passage from leaving new memory traces or, when familiar, from making contact with stored memory representation. Such a perceptual defect, when occurring along the melodic organization pathway, typically is associated with a right hemisphere infarct (Peretz, 1990; Liégeois-Chauvel *et al*., 1998; see Fig. 1). This lateralization effect was also observed in the present study. The large majority of patients (six out of seven) who were found to suffer from a deficit in discriminating melodies along the pitch dimension had sustained brain surgery on the right side of the brain. This right-sided surgery apparently interferes with melodic contour formation, as suggested here and demonstrated in several prior studies (Peretz, 1990; Liégeois-Chauvel *et al*., 1998).

Another important finding in the present study concerns the observation of a left hemisphere contribution to music recognition. A left-sided lesion was found to disrupt performance in all three tasks requiring recognition of melodies. Patients who underwent surgery on the left MCA generally displayed depressed performance in the recognition of recently studied melodies, in deciding whether a melody is familiar or not, and in recognizing the title of heard familiar melodies. This memory problem is a graded one in that it mainly emerges as a group effect. An obvious explanation for this left-sided bias to music memory is to relate it to the well-established superiority of the left hemisphere in verbal behaviour. This would indicate that left brain surgery would depress memory performance because of a diminished propensity to use verbal mediation as a mnemonic. This verbalization explanation is always difficult to dismiss even if the task requirements did not make any specific verbal demands. For instance, the memory recognition task of novel melodies and the familiarity decision test do not require any verbal mediation; only the identification test does. However, the music memory scores were found to be highly correlated with the logical story memory test scores ($r = 0.73$) of the Wechsler memory scale and not with the non-verbal visual reproduction score ($r = 0.04$) of the same scale. Thus, the left brain surgery patients appear to suffer from a verbal memory deficit as well. This verbal memory deficit might be the product of a mere association with the musical memory deficit, since the brain lesion can interfere with two adjacent, but nevertheless separate functions. This accidental association indicates that the left-hemispheric structures would be the depository of the music representation system depicted in Fig. 1 (and referred to as the 'repertoire' in previous studies; e.g. Peretz, 1996). Alternatively, if verbalization did contribute to the music memorization tests, then the memory impairment exhibited by the left brain-damaged patients would simply reflect the intervention of a verbal strategy. Future studies exploiting brain imagery techniques with normal brains should help to tease apart these two interpretations.

Whatever the exact interpretation of the left-side effect on music memory may be, the observed contribution of the left-hemispheric structures to the recognition of music coupled with the confirmation that right-hemispheric structures are instrumental in allowing perceptual access to these memories fit with classical views of agnosias. It is a recurrent proposal, even in the auditory domain, that apperceptive agnosia and associative agnosia are associated with damage to the right and left hemisphere, respectively. In the late 1960s, Faglioni and colleagues (Faglioni *et al*., 1969; later confirmed by Vignolo, 1982) proposed such a division of functions between hemispheres for auditory agnosias, i.e. for the recognition of non-verbal and non-musical sounds such as animal cries. These neurologists noticed that patients who were impaired in tasks requiring discrimination of the acoustic pattern of sounds had a right brain lesion. In contrast, a deficit in the identification of familiar environmental sounds (by pointing to visual objects as possible sources) was observed in left brain-damaged patients. These results have been confirmed recently by Schnider and colleagues (Schnider *et al*., 1994). A similar idea has been proposed for the recognition of voices (Van Lancker *et al*., 1988) and, in vision, for the recognition of objects (Warrington, 1985). The present study extends this view to the musical domain.

To conclude, damage to the territory irrigated by the MCA is likely to lead to deficits in music perception and recognition. These deficits are probably also related to the surgical manipulation that compresses the superior temporal gyrus and the structures hidden inside the sylvian fissure (which also hosts the primary cortex). Unfortunately, images of the lesions were poor due to the presence of metallic clips. The use of titanium clips will permit further studies with MRI technology. Nevertheless, the outcome of the present study shows that the scope of the disorders arising after MCA infarcts is wider than traditionally construed. Hence, it is likely that these patients will continue to offer a unique opportunity to study music-related deficits and also to investigate brain disorganization which gives rise to auditory disorders in general.

Acknowledgements

We wish to thank Carole Denault for testing most patients, and Frédérique Faïta for some of the testing of R.C. This research was supported by a fellowship from NSERC to J.A. and a research grant from the Medical Research Council of Canada to I.P. J.A. and I.P. contributed equally to this study.

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Received 3 December 1999. Revised April 10, 2000.
Accepted May 15, 2000