Auditory Atonalia for Melodies

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We present the detailed analysis of a patient, GL, who presents auditory atonalia as a consequence of brain damage. GL was found to be unable to use tonal knowledge in the interpretation of melodic closure, in discrimination as well as in preference of melodies. This breakdown in the tonal representation of melodic patterns occurred in the presence of accurate encoding of melodic contour and, to some extent, of interval sizes. It also occurred in isolation from disturbances in the processing of temporal information. Thus, the pattern argues against a general deficit in melodic organisation processes but, rather, argues for a specific loss of access to tonal knowledge. These data are discussed with regard to the independence and organisation of tonal knowledge within the music processing system and as a function of the current classification schema underlying musical disorders.

INTRODUCTION

Tonal knowledge refers to the system of mental representations that specify the set of pitches that can be used and the rules governing their combination in pieces written in our Western musical idiom. This implicit knowledge is considered to be the product of a shared experience that is acquired very early in the ontogenic development without explicit tutoring. Tonal knowledge is essential for organising most music, by helping memory, by allowing the building of expectancies, and by shaping singing performance. This range of mental processes in which tonal knowledge plays a central role is even larger in musicians, who exploit it in reading, in performing, and in composing musical sequences.

Accordingly, impairments of this knowledge may constitute a severe handicap for understanding and responding to the musical environment.

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However, the possibility that such impairments may be a critical factor in the occurrence of musical disorders following brain damage has rarely been assessed. The only supportive evidence that could be found was provided by Françès, Lhermitte, and Verdy (1973). In their study, a large group of aphasic patients was presented with pairs of short melodies and required to judge which tone in the melody had changed on the second playing. Melodies within a pair were either both tonal or nontonal. Aphasics failed to exhibit the normal superiority effect for tonal sequences over nontonal ones. This was taken as evidence that aphasic patients had lost tonal knowledge, thus accounting for their poor melodic discrimination abilities; it was referred to as melodic deafness.

What is remarkable about Françès et al.'s (1973) study is that they pioneered the field. They showed well before the first cognitive psychologists (Dewar, Cuddy, & Mewhort, 1977; Dowling, 1978) that tonal knowledge was central to melody discrimination, as described later. They also considered neuropsychological data relevant to theoretical development of normal cognition, well before many of us. Yet their study may have suffered from this anticipation. First of all, task difficulty may account, at least partially, for the results; the patients were performing close to chance and only half of the normal controls showed the tonal superiority effect. Secondly, the outcome of the aphasic group may have been the product of averaging together different types of amelodic disturbances, as will be clarified later. Indeed, only one experimental test was used and the mode of the score distribution was taken as the relevant outcome. Demonstration of a true disturbance in tonal interpretation of pitch, as opposed to difficulties that arise from other sources, requires the careful use and analysis of multiple tasks. In this respect, the detailed analysis of a single case may be more appropriate. The present study represents just such an attempt. However, before turning to the study, its relevant background will be reviewed.

Cognitive Studies of Tonal Knowledge

There is now considerable agreement on the notion that musical pitch perception reflects knowledge about how pitches are typically used in tonal music. The basic idea is that musical pitch perception is recoded in forms that are quite different from the sensory encoding of frequency—that is a necessary stage for perceiving pitch height or pitch interval size.¹ Such

¹Pitch height and pitch interval size will be used interchangeably here. The idea is that pitch height is probably not used in absolute terms in a melodic context and thus is best characterised with respect to the interval size between two adjacent pitches. The main point is that both pitch height and interval size refer to the encoding of the pitch dimension along a frequency continuum.
recoding of pitch, presumably mediated by several cognitive operations, reflects contact with tonal knowledge. This knowledge incorporates several constraints about the pitch collections that can be summarised as follows.

In our musical idiom, the set of musical tones consists of a finite ensemble of pitches, roughly corresponding to the tones of the piano keyboard. Moreover, only a small subset of these pitches are generally used in a given piece, i.e. those from a particular musical scale. The most common scale used in popular Western music is the diatonic scale, which contains seven tones, repeated at octave intervals. The structure of the scale is fixed and asymmetrical in terms of pitch distance. It is built of five whole steps and two half steps. Scale tones are not equivalent and are organised around a central tone, called the tonic. Usually, a piece starts and ends on the tonic. Among the other scale or diatonic tones, there is a hierarchy of importance or stability, with the fifth scale tone—often substituting for the tonic—and the third scale tone being more closely related to the tonic than the other scale tones. Together, the tonic, the third, and the fifth form what is referred to as a major triad chord, which provides a strong cue for the sense of key. The remaining scale tones are less related to the tonic, and the nonscale tones are the least related; the latter often sound like “foreign” tones.

There is substantial empirical evidence that listeners use these tonal characteristics in listening to musical pitch structure, albeit in an implicit manner. However, only the studies that are most directly relevant to the present one will be summarised here (see Krumhansl, 1990, for a more extensive review). These studies revealed effects of tonal organisation with melodic sequences (as opposed to chords only) in nonmusicians (as opposed to musicians only). As previously noted, one of the earliest observations of the use of tonal knowledge in melody processing is the tonal superiority effect observed in discrimination. Adult listeners, as well as young children, perform generally better in melody discrimination when tones conform to the tonal system than when they do not (Dewar et al., 1977; Françes, 1972; Trehub, Cohen, Thorpe, & Morrongiello, 1986; Zenatti, 1969). Another manifestation is the scale violation effect; listeners readily detect a tone that departs from the scale of the melody in contrast with a tone that respects it (Bharucha, 1984; Cuddy, Cohen, & Miller, 1979). Tonal structure also affects musical preferences. Western listeners have an aesthetic bias for tonal sequences; they prefer melodies that are most constrained in terms of tonal rules (Cross, Howell, & West, 1983; Smith & Melara, 1990). Finally, sensitivity to specific aspects of the tonal structure is reflected in the subjects’ ability to identify particular elements within the scale as being most central, like the tonic and the fifth, via the judgments of good completion of melodic patterns (Cuddy & Badertscher, 1987; Janata & Reisberg, 1988).
Although the evidence for the contribution of tonal knowledge to melody processing is compelling in a normal brain, little is known about the conditions under which brain damage interferes with it, apart from the suggestive but isolated results of Françoës et al.’s study. In contrast, we have already accumulated some knowledge about how brain damage can result in amusia in nontonal aspects of musical behaviour. Knowing along which principles amusia can occur will allow us to specify better the context in which a disruption of tonal processing (referred to as atonalia) can be expected. We will thus turn to this neuropsychological background.

Breakdown Patterns in Amusia

It is a well-established fact that music, as a faculty, is autonomous from the rest of the cognitive system. Most notably, amusia can occur without aphasia and vice versa (see Marin, 1982, for a review). Yet, the idea that the music faculty could be decomposed into a set of distinct components, each having the potential to be disrupted by brain damage, has only received empirical support recently (Peretz, 1990). These data from amusic cases were found to complement the cognitive investigation of normals in providing quite specific information regarding music perception. Two such arguments from amusia are relevant here and will be considered. First, there is evidence that amusic performance delineates two distinct processing sub-systems devoted to the processing of melodic information and to the processing of temporal information, respectively. Second, there is a suggestion that the performance of some amelodic patients provides support for a two-component model of melody abstraction.

The notion that breakdown patterns in amusia can be divided into two major categories, qualified as amelodia and arhythmia respectively, arises from several independent observations. Recently, we have shown that impairments in melody discrimination can occur while rhythmic discrimination is spared, and conversely, rhythmic discrimination can be profoundly disrupted while melodic discrimination is intact (Peretz, 1990). This double dissociation was found to be a robust phenomenon that could not be explained by a single system functioning at different levels of efficiency: This was attested by the observation of a reversed association following Dunn and Kirsner’s (1988) logic in a further case of amelodia without arhythmia (Peretz & Kolinsky, in press). These findings extend to the perceptual domain a dissociation that was already reported in other spheres of musical behaviour such as singing (Brust, 1980; Dorgeville, Note 1; Movlov, 1980) and reading (Assal, 1973; Brust, 1980; Dorgeville, Note 1).

Each of these distinct neuropsychological conditions, referred to as amelodia and arhythmia, corresponds to a broad category that invites further decomposition. With respect to amelodia, it is possible for at least
two distinctive components to be disrupted selectively, and thus for two types of amelodia to result. We have already documented several cases of amelodia arising from a profound disturbance in the processing component devoted to the abstraction of melodic contour (Peretz, 1990). Contour processing refers to the representation of a melodic sequence in terms of pitch directions, independently of its specific pitches or intervals. Its contribution to melody processing is well established (see Dowling, 1982, for a review) and is easily observable in "same–different" classification tasks. Under these conditions, contour-violated comparison melodies are far easier to discriminate than contour-preserved melodies, particularly when the melodies to be compared are transposed at different pitch levels (Dowling, 1978; Peretz, 1990; Peretz & Morais, 1987). Five amelodic patients, having sustained a lesion in the right hemisphere, were found to be completely unable to use melodic contour under such conditions. This particular failure was taken to be the functional origin of their severe amelodia. Other patients with amelodia were found to suffer from an impairment in the abstraction of the precise pitch intervals in melodies. These patients could still use contour as a discrimination cue but failed to discriminate or recognise melodies when contour was not available or discriminant. The lesion responsible for this type of amelodia was localised in the left hemisphere (Peretz, 1990).

The claim that the mechanisms involved in contour abstraction are likely to be distinct from the ones involved in interval abstraction is relatively uncontroversial, given the dissimilarity of the codes over which these computations are performed and given the large body of empirical evidence showing their distinctive role in melody processing (see Dowling, 1982, for a review). We consider here the possible existence of still another processing component, devoted to the tonal interpretation of pitch, whose disruption might be a critical factor in the occurrence of amelodia.

The ensuing question is thus to justify the plausibility of conceiving three distinct components, probably hierarchically organised, for building an accurate representation of the pitch sequential structure of a melody. The problem lies essentially in distinguishing between an interval-based component and a component devoted to the computation of tonal function. One may argue that there is no such distinction and that intervals are merely the input code and tonal functions the output code of a single tonal component. Since tonal encoding of intervals would be a mandatory process (but see Dowling, 1986), its operation would prevent access to the earlier codes in terms of "absolute" distance; these codes would be lost or confounded with their tonal transformations.

However, there are reasons to conceive of the existence of an interval processing component that is relatively independent from the tonal component. First of all, not all music is tonal. Thus, in order to grasp pitch
systems different from the tonal one, listeners must be able to abstract from interval information either new scales or at least representations of pitch structure that are sufficiently precise to allow organisation of the melodic pieces into segments, recurrent motifs, and so on. Contour information is too crude an index for conveying such an information. Secondly, even with tonal music, we quite often experience acute perception of mistuning, suggesting that we do keep a record and have access to interval information that is not tonally categorised. These arguments are, however, indirect and thus remain speculative in the absence of empirical evidence. Nevertheless, we take it as a reasonable departure to assume that a patient encountering tonal encoding difficulties may still rely on an interval-based procedure for encoding melodies. In the present study, we will try to assess this hypothesis.

The Present Case Study

In this study, we present the detailed analysis of a patient, GL, whose amelodic disorder seems to be of a higher order than that sustained by previously studied amelodic patients with unilateral brain lesion (Peretz, 1990). We present evidence that GL’s disorder arises from an impairment in tonal encoding of pitch. Essentially, the aim of this study was to address two questions. Given that tonal knowledge may be subserved by a distinct processing component, (1) can it be the object of selective disruption as a result of brain damage? and (2) what can such a deficit tell us about existing models of normal music cognition? Our main predictions were that impairment of tonal knowledge would restrict perception of pitch structure to a uni-dimensional continuum of pitch height (i.e. intervals) and of pitch directions to an ordinal dimension (i.e. contour). As a consequence, the patient should encounter specific difficulties with melodic as opposed to temporal patterns, encounter memory difficulties for pitch material (Dowling, 1978), and be relatively insensitive to tonal structure in perception as well as in expression (i.e. through singing in the present case, since the patient is a nonmusician).

These predictions were assessed in different sections, as follows. In section 1, we discuss GL’s performance on a series of screening tests used to classify patients in terms of the amelodic-arhythmic distinction. The subsequent two sections are then devoted to the experimental study of GL’s amelodic deficit, by assessing his memory capacities (section 2) and his encoding procedures (section 3) used in melody apprehension.

CASE HISTORY

GL is a 61-year-old man who was the head of a small business. In 1980, at the age of 51, he presented with a first aneurysm on the right middle cerebral artery, which was clipped. Upon recovery from the first surgery,
he had no sequellae and thus went back to work. A year later, control evaluation showed the existence of a mirror aneurism on the left side, which was also then clipped. After the second operation, GL presented severe Wernicke’s aphasia and amusia, but no other neuropsychological deficit. He quit his job and underwent speech therapy for two years. He recovered most of his speech abilities. Since then GL has lived autonomously, like any well-off retired person. In August 1990, a control C.T.-scan was performed and confirmed sequela bilateral lesions, one in the left temporal lobe and one in the right fronto-opercular region.

GL was referred to us in 1989 because of his persistent amusia. In describing his amusia symptoms, GL stated that he was totally unable to pick out familiar music and did not enjoy music any more. His musical background is that of a nonmusician who was nonetheless an avid listener to popular and classical music, attending concerts and musical recitals very regularly before his illness. All the data reported here were collected between September 1989 and October 1990, when GL was about 10 years post-onset.

GL has completed 14 years of formal education (including 2 years as an undergraduate in pharmacology) and is strongly right-handed as assessed by the French adaptation of Oldfield’s (1969) questionnaire. He achieved a W.A.I.S. full scale I.Q. of 120 (verbal: 111; performance: 122), reflecting his lack of serious aphasic impairment and his high educational level. He obtained an Ottawa-Wechsler Memory Quotient of 107. He had no ideomotor apraxia, no dyscalculia, nor any visual discrimination difficulties. His receptive and expressive speech was assessed with different aphasic battery sub-tests. No apparent deficit could be detected on these tests; notably, he obtained a normal score (32/36) on the short version of the Token Test (De Renzi & Faglioni, 1978), which is taken as a highly sensitive measure of speech comprehension deficits. Contrasting with his relatively good linguistic abilities, recognition of tunes (without lyrics) was totally abolished. Out of 140 musical excerpts (including his national anthem) that are very familiar to everybody in Quebec, he could not identify a single one. This complete agnosia for tunes appeared as a selective deficit since he did not experience any comparable difficulty with the identification of auditory events in other domains (such as animal cries, environmental noises, and musical instruments; see Peretz et al., Note 3, for further details). Therefore, initial testing of his residual musical perceptual abilities was undertaken in order to determine whether GL’s music agnosia could be explained by perceptual difficulties.

Since the results of these initial investigations prompted the present study, the relevant elements will be presented in the next section along with complementary diagnostic tests. Unless stated otherwise, GL’s performance was compared in section 1 with that of a group of 5 normal controls matched in sex, age, and education drawn from our former study
(Peretz, 1990; age mean: 63.6 yrs, range: 49–76; education mean: 14.2 yrs, range: 13–17) and, in section 2 and 3, with the data from a new group of 5 normal controls closely matched to GL in all relevant aspects (mean age: 61.6, range: 59–66; mean education: 15.2, range: 13–17).

SECTION 1: DIAGNOSTIC MUSICAL TESTS

As a departure point for the present study, GL was tested with a battery of 7 subtests described in detail elsewhere (Peretz, 1990). This battery aims at assessing the discrimination of various musical aspects that are known to contribute to music processing, at the same time keeping the material as natural and constant as possible across conditions. The material consists of a pool of 24 novel but tonal musical sequences, that are arranged in different conditions. The results are presented in Table 1.

In the “isolated pitch” condition, 2 piano tones were presented successively and the task was to judge whether their pitches were identical or not. When different, the pitch distance varied from 3 to 10 semitones. This test aimed at verifying that the pitch changes inserted in the melodic conditions were well perceived when presented in isolation. GL’s performance was quite high (20/24) but slightly inferior to the lowest score of normal subjects (22/24). However, when presented with synthesised complex tones (from Peretz, Paquette, & Lecours, Note 3) and required to perform the same task, GL’s only error out of the 60 trials presented was to miss one semitone difference. His performance fell well within the range of 24 normal subjects

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*Mean and range.
of his age (taken from Peretz et al., Note 3, see Table 1). Thus, GL does not seem to be impaired in judging the pitch difference between 2 successive tones when these are presented in isolation.

An impairment in pitch judgments appears, however, when these have to be made in a melodic context. As it can be seen in Table 1, various tests were used with melodies as stimuli. In the contour-violated and the contour-preserved conditions, pairs of melodies had to be classified as “same” or “different.” When different, a pitch change—of the same magnitude as one tested in the “isolated pitch” condition—was inserted in the second melody. This pitch change modified the contour—that is the pitch direction—of the original melody in the contour-violated condition, and respected the contour in the contour-preserved condition. In these two conditions, GL’s performance was below the normal range. However, he did perform better in the contour-violated condition (with 6/8 on “same” and 11/16 on “different” trials) than in the contour-preserved condition (with 6/8 on “same” and 7/16 on “different” trials), exhibiting normal sensitivity to the presence of contour as a discrimination cue. Note, however, that GL’s performance is just below the lowest score of controls. Therefore, to ascertain whether this was a real effect, we presented GL with the same contour-preserved task, but with new material composed of equitone melodies, involving nine tones each (see the unidimensional condition in Table 1). GL again performed below the normal range. Thus, GL’s performance on these tests would classify him in the interval-impaired type of amelodia, although moderate in severity. Indeed, GL seems to be able to use interval information to some extent, whereas our former amelodic patients classified in the same category could not.

The last melodic condition, referred to as tonal closure in Table 1, was intended to assess the use of tonal knowledge in judging melodic closure. In this test, 8 melodies used in the previous conditions, in which all temporal variations were removed, were presented with either the tonic or a nontonic tone at the end. The nontonic ending was diatonic (in the key of the melody) and was chosen so that it was as close as possible in pitch height to the tonic (i.e. within a maximal distance of 2 semitones). All the endings followed a descending pitch direction. Each stimulus was presented twice in a random order. Subjects were required to indicate whether the melody was complete or not when we stopped the recording (as in Imbert, 1981). As can be seen in Table 1, GL’s score was at chance (chance being 50%). He responded equally often with “complete” and “uncomplete.” His responses were not random though: He was remarkably consistent on specific melodies, changing his judgment only once out of the 16 opportunities. Thus, further analyses were performed in order to assess whether nontonal features, such as the number of occurrences of the last tone within prior tones, might have influenced his judgment. None of these analyses
could account for his pattern of responses in any systematic function (but see Experiment 5, in section 3). Since controls excelled on this task, GL exhibits a clear deficit in this test. In addition, his deficit intrigued us because we found relatively better performance in another amelodic patient, CN, on the melodic closure test for whom the task was originally designed. CN obtained 20/32 on this task, although she did far worse than GL on all of the melodic discrimination tasks described earlier (Peretz et al., Note 2; Peretz & Kolinsky, in press).

Finally, in order to assess memory for pitch, we used Gordon’s (1983) tone-span task. Although this is a crude test of short-term memory, it was administered to GL as a first approximation of his memory for pitch. The items were sequences of high and low tones (a musical fourth apart) sung at the rate of one tone per sec. and recorded on tape in a specific order. GL was asked to sing back the sequences, which began with two tones and progressively increased up to seven, unless he made two consecutive errors. The procedure was repeated four times. The correct repetition of the tones in the right order was considered a correct response. In fact, GL did not sing back the tones as required but recoded the high-low pitches in the words “one-two,” after presentation. This verbal translation procedure may have somewhat diminished his span, since it delayed recall. Yet, GL’s span was found to be five, which is above the cut-off span of four, considered to indicate a deficit in tone span.

Contrasting with GL’s poor performance on the melodic dimension, his scores were mainly in the normal range in the conditions assessing temporal organisation abilities (see Table 1). Since his score was near the lowest extreme of the normal range, we employed a further test. In this test, 2 equitone sequences, involving 9 tones played at the same pitch each, had to be differentiated. A temporal difference was inserted in the fourth, fifth, or the sixth serial tone. He obtained a score of 17/20 correct, which is well within the normal range (14–20). This result confirms that GL does not present evidence of arhythmia. Thus, after CN (Peretz & Kolinsky, in press), GL is the sixth case of dissociation between the processing of pitch patterns and the processing of temporal patterns that we have documented, counting the 4 cases of our previous study (Peretz, 1990).

The question arose as to whether a tonal loss for pitch can be the product of damage to a single central system that governs both perception and expression. To test this notion, we attempted to engage GL in singing.²

²In contrast with his outstanding collaboration in perceptual tasks, GL’s compliance to singing requests was rather limited. He refused to sing back (i.e. to repeat) any new material presented to him, as well as to sing songs of his choice or songs prompted by titles. He claimed that he could not remember any of them. Yet, we noted that GL sang along spontaneously with excitement when presented with some well-known tunes that he could no longer overtly recognise. Therefore, we decided to exploit this behaviour to collect singing material.
Thirty fragments of well-known melodies (from 10 to 27 tones in length) were presented to him on a keyboard. He was required to sing back as much of the fragment as he could remember, thus performing a sort of repetition task. He refused to sing back 4 of the fragments. In 7 other cases, he sang a totally unrelated and unrecognisable tune; we will refer to these as improvisation songs. Thus, there remained 19 singing responses that could be analysed with reference to the stimulus. These responses were analysed independently by 2 musicians, who were required to assess the number of tones that were accurate (or acceptable) renditions of rhythm, melodic contour, intervals and key, for each production. For the latter aspect, tonal accuracy of his production was judged in relation to the possibility of assigning his song pitches to a common key, irrespective of the specific key of the presented song fragment. Despite the rather crude index that these measures provide about GL’s singing performance, correlations between the ratings of the 2 judges were very high for rhythm \( r = 0.91 \) and contour \( r = 0.93 \) and slightly lower for the interval-related judgments \( r = 0.76 \) and 0.73, for the intervals and key, respectively). Given that each of these correlations was significant (at \( P < 0.001 \)), subsequent analyses were performed on the average ratings.

In his 19 recognisable attempts to sing back the model, he produced 87.9% of the tones presented. Out of this production, 77.7% of the tones were judged to be an accurate rhythmic rendition of the model and 68.3% to follow the contour accurately. In contrast, only 43.4% of the tones were judged to respect the interval sizes (for example, see his rendition of Frère Jacques in Fig. 1). Finally, the most interesting feature was that GL’s production was found to be tonally coherent; 72.2% of the tones produced were judged to be consistent with a single key and even to end in some cases in a perfect cadence (see Fig. 1). GL was thus singing in tune for our Western ears. More importantly, this was also true of his improvisation songs: 80.8% of the improvised pitches were judged to be tonally coherent (see an example of these improvisations in Fig. 1).

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**FIG. 1** Examples of transcribed singing renditions of GL.
There are doubtless many other analyses that these results could accommodate. Nonetheless, these analyses allow us to draw quite important conclusions regarding GL’s residual abilities in singing as opposed to perception. In general, GL’s singing performance closely follows the pattern observed in perception for all musical aspects but tonal structure; rhythm and contour are well presented whereas pitch intervals are only approximate. However, unlike his perceptual abilities, GL exhibits some implicit tonal knowledge, by producing songs that respect tonal constraints. Yet, this finding relied on aural judgments of literate musicians, who may have attributed more coherence to the song pitches than there actually was (see Sloboda & Parker, 1985, for the discussion of the advantages and pitfalls of this method). Since there was no clear alternative for collecting and analysing more formally GL’s singing behaviour, the present results constitute the only element of information regarding his expressive skills. However limited, these data seem noteworthy because GL’s apparent dissociation between perception and production can be regarded as a first suggestion for incorporating distinct processing mechanisms in the receptive and expressive aspects of music behaviour.

In summary, GL’s amusic deficit is attributed to a primary deficit in his perceptual representation of sequential pitch structure, and this deficit coexists with intact rhythm perception. Thus, GL appeared to present amelodicia, in the sense that he performed below normals in the processing of melodies, particularly when intervals required tonal interpretation. Contour cues seemed to be used properly and processing of intervals in isolation appeared normal. Thus, the pattern of results points toward a sequential problem in encoding tonal pitch intervals.

The question remains as to whether GL’s tonal encoding deficit reflects a true disruption of tonal knowledge or whether it was rather due to task parameters. In general, GL’s performance appeared within the range of control performance on the easy tasks (with the notable exception of the melodic closure test; see Table 1) and below normal on the more difficult tasks. This raises the possibility that GL has a general deficit in processing music that the easy tasks are not sensitive enough to detect. Although we will not provide unequivocal evidence for elimination of this potentially confounding factor, we will attempt to make the argument stronger by searching for convergence across multiple experimental settings.

Another potentially confounding factor that merits careful consideration is short-term memory. GL’s particular difficulty with tonal closure might arise from a deficiency in short-term memory for pitch, since this test requires retention of relatively long segments of pitch information. Although GL’s span appears to be normal, his performance on the specific tone-span test could be attributed to his preserved capacity to use contour information. Yet, distinguishing between tonal encoding and pitch memory
is very difficult since these two factors are intrinsically related in a melodic context. Memory for unrelated pitches is very poor and one of the fundamental roles of tonal encoding is precisely to provide the relevant framework for keeping an accurate record of melodic pitches, as indicated in the Introduction. We conjecture, however, that distinguishing between the two factors is possible. If GL’s deficit is due to a defective memory buffer for pitches and not to a deficient tonal encoding, he should exhibit sensitivity to the latter factor when dealing with infra-span melodies. Alternatively, if his problem is one of tonal encoding and not of pitch memory per se, GL should still be unable to use tonal cues but succeed with the other ones, such as contour and interval sizes, even when the tones fall within his span. Experimental examinations of these two alternatives are presented in Sections 2 and 3, respectively.

SECTION 2: TESTS OF PITCH MEMORY ABILITIES

Experiment 1: Memory for Pitch

Pitch information is retained in a specific system, possessing particular properties (see Deutsch, 1975b, for a detailed review). These properties have been revealed using the paradigm of delayed pitch comparison. In this task, subjects are required to compare two tones for pitch when these are separated by an interval during which there is interpolated material. Manipulation of the pitch distance of the interpolated tones can produce either memory facilitation or interference (Deutsch, 1972; 1975a). Although the mechanism responsible for these particular effects requires theoretical development, the phenomenon is robust and specific to the pitch memory system. Therefore, this research provides us with an appropriate tool for examining whether or not GL has an impairment at this level.

We employed a version of the task adapted to the testing of brain-damaged subjects (Zatorre & Samson, in press). As in Deutsch’s work, the task consisted of judging whether a target tone and a comparison tone had the same pitch or not. In one condition—the control condition comprising 24 trials—the interval (of 1650msec) between the tones was silent; in the other condition—the interpolated condition comprising 72 trials—the interval was filled with 6 distractor tones. In the second serial position of these interpolated tones, a tone was placed whose pitch bore a critical relationship to the target tone. In one third of the “different” trials, it was identical. In another third, the critical interpolated tone differed from the target by a whole tone. In the remaining trials, the tone was distant by more than a whole tone from the tone to be remembered. The first case was expected to yield memory facilitation, whereas the second case was
expected to produce some disruption, compared to the last condition that served as the baseline. All the other distractor tones were produced in a different pitch range (i.e. a different octave). The tones to be compared were identical in half the trials and different in the other half. When the comparison tone differed from the target, it was by 1, 2, or 3 whole-tone steps.

GL was expected to encounter no difficulty in the control condition, on the basis of the isolated pitch discrimination tasks described in Section 1 (see Table 1). The critical condition was therefore the interpolated condition. If GL’s amelodia is essentially due to a poor pitch memory system, his score should drop drastically in that condition. Moreover, the qualitative manifestations of a normally functioning short-term memory for pitch should be lacking or completely erratic.

Results and Comments

As expected, GL performed well (with 22/24) in the control condition. In the interpolated condition, however, his performance showed a decrement (with 55/72) that was significantly below control subjects’ performance (mean 66.4; \( \chi^2 = 5.68; P < 0.02 \)). Yet GL achieved 76.5% correct, which is not far below the lowest control score of 81.9% (59/72) and which is reliably above chance (of 50%, \( P < 0.001 \), by a binomial test). Therefore, GL’s pitch memory is not severely impaired. Moreover, his pattern of responses reveals sensitivity to the same factors as normals, as described in more detail below.

GL’s performance was first examined as a function of the pitch distance between the target and the comparison tone. His scores expressed in percentage correct, as well as those of controls, are plotted as a function of pitch distance, with zero (“same” trials), one, two, or three whole tones, in Fig. 2. As can be seen, GL’s sensitivity to pitch distance is parallel to that of the matched controls. All subjects improved as the pitch distance between the target and the comparison tone increased.

The second analysis investigated the influence of the critical interpolated tone on discrimination. Hence, performance was analysed as a function of the pitch distance between the target and the second tone in the distractor series, following Deutsch’s (1972; 1975b) procedure. As can be seen in Fig. 3, GL showed evidence of facilitation (i.e. a repetition effect), making fewer errors when the distractor was identical to the target than when it was more than a whole tone apart (the dotted baseline). He also showed memory interference when the distractor was close in pitch to the target (i.e. a whole tone distance). Average control data failed to show facilitation; this was probably due to a ceiling effect (baseline performance was at 91.6%, thus leaving little room for the emergence of the effect). Nevertheless, GL’s performance is qualitatively similar to the one repeatedly
reported in the normal literature. This suggests that his pitch memory system is functioning normally, although slightly less efficiently than a neurologically intact system. The locus of this general decrement remains to be determined.

One plausible source for the general decrement that arises from the tonal loss hypothesis is that delayed pitch comparison is not realised solely on a frequency continuum representation of the tones, but rather involves more elaborated representations of pitch. That such elaboration indeed incorporates tonal knowledge has been demonstrated by Krumhansl (1979) using the same pitch delayed comparison task. Subjects were more accurate when distractors were taken from a common scale than when they were not. It should be recalled here that the critical interpolated tone was the only sound to be within the same octave as that of the tones to be compared and to be related to the target (as well as the comparison tone) by whole tone steps. Thus, all critical tones (target, second distractor and comparison) could be segregated from the other distractors on the basis of pitch proximity and could possibly be anchored in a common diatonic scale. This additional anchoring may have facilitated normals’ pitch discrimination (thus yielding ceiling effects) but not GL’s discrimination judgments, which had to rely on a frequency continuum. This interpretation is speculative at this stage but will be supported in the following section.
FIG. 3 Percentages of correct pitch differentiation as a function of the pitch distance between the target tone and the second interpolated tone. These were either identical, a whole-tone apart, or more than a whole tone (baseline measure). The top panel represents GL's data, the lower one the controls' data.
In any case, some aspects of the present results are important to emphasise, since these will help to interpret further results. GL was able to retain pitch information across eight different tones with a fair level of accuracy. Moreover, he benefited from repetition. Thus, lack of tonal interpretation can be explained neither by a deficit in retaining pitch information nor by a deficit in using repetition (the latter being considered as most determinant in conveying relevant information for deriving the key of successive pitches; Krumhansl, 1990).

**Experiment 2: Chunk Formation**

Although absolute pitch retention contributes to melodic organisation, its role is known to be limited. Memory for melodies relies heavily on melodic features that are relational and more abstract. One of the basic and central processes that facilitates memory consists of grouping contiguous events into units larger than isolated pitches. The formation of such chunks is one efficient and well-established tendency that the human short-term memory system uses as a means of increasing its limited capacity. That such a chunking process occurs in music is posited by most theorists (Boltz & Jones, 1986; Deutsch & Feroe, 1981; Lerdahl & Jackendoff, 1983; Tenney & Polansky, 1980). Moreover, the rules governing the formation of musical chunks have become the subject of increasing empirical research (Deliège, 1987; Dowling, 1973; Peretz, 1989; Peretz & Babaï, 1992). Therefore, we are in a position to assess GL’s chunking abilities and verify whether or not this essential memory process is faulty.

To this end, we generated 14 melodies that were organised in such a way that half were composed of 3 groups of 3 tones each, and half were not. Delineation of group boundaries was created by introducing a pitch skip combined with a contour reversal. These boundaries have been shown to be a powerful determinant of chunk formation (Peretz & Babaï, 1992). For the unstructured melodies, care was taken not to use these boundaries and thus make their chunking either less clear or impossible. The melodies were presented in a target recognition task, following previous results showing sensitivity and accessibility of this task for nonmusicians (Peretz, 1989). Subjects were presented with a 3-tone target followed, after a 2sec silent interval, by one melody. They were required to judge whether or not the target was part of the melody. In half the trials, the target did not occur in the melodies. These foils were, however, very similar in structure to the melodies used in the positive trials; half of them were structured and contained tone series that were close in terms of contour and interval sizes to those used in the targets. In the positive trials, the target was embedded in the central serial position of the melody. The same target occurred once in the context of a structured melody, and thus fell just in-between 2 melodic boundaries, and once in the context of an unstructured melody.
(see Fig. 4). Targets delineated by melodic boundaries were expected to be easier to recognise than the ones that were not (i.e. the ones embedded in the unstructured melodies). This observation would indicate that the boundaries were perceived and used to chunk the melodies.

Since GL was shown to be able to use contour (in Section 1) and pitch intervals to some extent (in Section 1 and in Experiment 1), a problem with this task would indicate an impairment in using this information for forming adequate chunks in melodies. Such an impairment would easily explain a memory deficit for melodies. Note that in terms of memory load for individual tones, the present task is at least as demanding as that of Experiment 1: The three tones of the target must be maintained in short-term memory and compared to at least six other potentially interfering tones that cannot be ignored here. However, if the target tones are held in memory as a single group unit, then GL may perform relatively better than in Experiment 1, since the chunking strategy should reduce the memory load considerably.

**Results and Comments**

GL was rapid and accurate in performing this test; he was correct on 23/28 trials (82.1%). This score falls well within the normal range (19–25; mean: 23.2, or 82.9%). He also displayed an advantage for the structured context (with 6/7) over the unstructured one (3/7). This effect was also found in normals (with 4.8 versus 4.4, respectively), for whom the difference was, however, smaller than expected. Yet one control subject obtained exactly the same results as GL. Thus, despite the fact that the task was not very sensitive to the effects of chunking in normals, we can conclude that GL has no difficulty in organising melodies in small chunks using pitch proximity and contour continuity factors. Moreover, it appears

![FIG. 4](image-url)  
**FIG. 4** Example of trials used in Experiment 2, where the target was either embedded in a structured melody (and thus corresponded to one of its chunks) or in an unstructured melody (thus without any clear cue for chunking).
that by grouping tones in larger units, GL succeeds in performing normally with melodies.

**Experiment 3: Melody Length**

In order to test the tonal loss hypothesis in a melodic context, one often needs melodies of a length of at least five tones to allow the establishment of a given key (e.g. Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982). GL seems to be able to deal with tone sequences of such a length; in Experiment 1, he performed with a reasonable degree of accuracy for eight tone sequences and, in Experiment 2, he did so with six to nine tone sequences. However, tests of tonal encoding are sometimes of the “same–different” classification type, as will be clarified later. In this type of task, comparison of two melodies, and thus twice the number of tones, is required. We already know that GL does well with three-tone melodies, since that is basically what was required in Experiment 2. Yet, we do not know what the upper limits of GL’s memory capacity are in such conditions. Discovering this limit was the goal of the present experiment.

Melodies of 3 different lengths, i.e. comprising 3, 6, and 9 tones each, were used in a “same–different” classification task. There were 24 blocked trials at each melody length. Half of the trials consisted of an identical pair, and half contained a change in the comparison melody. When melodies were different, it was by the last group of 3 tones. In half the trials, the changed group violated the contour of the target melody, in the other half it did not. Increasing melody length was accomplished by keeping the pitch sequences used in the previous length and adding 3 new tones. Thus, the melodies remained constant across conditions except for the last 3 tones (see Fig. 5). Finally, an attempt was made to create melodies that lent themselves to chunking by 3 tones, following the same procedure as the one used in Experiment 2. The idea was that if GL relied heavily on this strategy, he might try to apply it to all melodies. Thus, control for this eventuality was highly desirable across conditions.

![Target](image)

**Target**

![Comparison](image)

**Comparison**

**FIG. 5** Examples of “different” trials used in Experiment 3, where melodies contained either three, six or nine tones. The difference always involved the last group of three tones.
Results and Comments

Results of GL as well as those of normal controls are presented in Fig. 6. As can be seen, GL was markedly affected by melody length; his performance was almost perfect, with 93.8% correct with 3-tone melodies, but it dropped to 62.5% on the 9-tone melodies; this level did not differ significantly ($P < 0.05$) from chance (by a binomial test). Note, however, that with 6-tone melodies, GL’s performance is reliable (79.2%) and thus provides the answer to our main question. That is, GL is able to perform above chance on “same–different” classification tasks with melodies containing up to 6 tones.

GL again showed sensitivity to the presence of contour as a discrimination cue: in the 3-tone length condition, he only made errors on the “same” responses, but in the 6-tone condition he made errors on 2 of the 12 “different” trials, which were both contour-preserved melodies. Yet he did succeed in differentiating the other 4 contour-preserved comparison melodies. This suggests that GL is able to discriminate contour-preserved melodies, and thus use interval information to some extent. The contour effect was absent in the 9-tone conditions; this result might be due to his generally poor performance. Thus, taken together, these results are consistent with the contour superiority effect found in our screening tests (see Section 1), but also show more clearly that GL has a short-term memory deficit for melodic information.

![Graph showing percentages of correct responses as a function of melody length in Experiment 3](image)
In the present experiment, there was an opportunity to chunk the melodies into units larger than individual tones. Therefore, as demonstrated in Experiment 2, it is very likely that GL used that strategy. If so, the present results would imply that his span for melodic chunks is about four (i.e. two chunks in the target melody plus two chunks in the comparison melody, as can be inferred from the six-tone length condition): This estimate is close to his span for isolated pitches, which was five (see Section 1). However, here, we have evidence that this performance is below what can be expected from a normal short-term memory system for melodic material.

**Summary of GL’s Pitch Memory Difficulties**

Following the tonal loss hypothesis, a short-term memory deficit was expected in GL and was indeed demonstrated. Moreover, this deficit could not be explained by some disruption in nontonal encoding procedures, neither as a poor encoding of pitch information (Experiment 1) nor as an impaired ability to form melodic chunks (Experiment 2). It remains to be demonstrated, however, that GL’s short-term memory deficit results from, or at least is associated with, true disturbances in tonal encoding procedures for pitch intervals. Indeed, the marked length effect observed in Experiment 3 may question the inference made about his chance performance in the melodic closure test used in Section 1. This test used melodies from 8 to 15 tones long, if we ignore repetition of the first phrase.

The idea that his main source of difficulty arose from a profound disturbance in tonal encoding and not from memory limitations was considered in the following section by using melodies of six tones or fewer, that is with melodies falling largely within his memory capacity. Most theorists agree that a tonal interpretation of a melodic sequence must be made with almost no delay, and based on a limited number of events. To the extent that such tonal procedures are functional, listeners will commit themselves to an interpretation very early in the listening process. Unlike normal listeners, GL is not expected to engage in such a process.

**SECTION 3: TESTS OF TONAL ENCODING OF PITCH**

**Experiment 4: Scale Violation Effects**

Cuddy et al. (1979) have shown that listeners make fewer errors in melody discrimination when a pitch change is a nondiatonic tone within a diatonic sequence than when the pitch change is taken from the same diatonic context. Thus, changes that violate the diatonic structure are easier to detect than changes that do not. A task that exploits this scale violation
effect, as well as the contour violation effect, and that has already been validated with nonmusicians as well as brain-damaged subjects, is the one used by Zatorre (1985). The task is to judge whether two successive six-tone melodies are the same or different. When the melody differs, it is by the fourth serial tone, whose pitch is altered in four different ways. In the SS condition (Same scale, Same contour), the pitch preserved both the scale and the contour of the target. In the DS condition (Different scale, Same contour), the pitch violated the scale but not the contour of the original melody. In the SD condition (Same scale, Different contour), contour was violated but not the scale. In the DD condition (Different scale, Different contour), both contour and scale were violated. The advantage of this material is that the use of scale characteristics as discrimination cues can be contrasted with the use of contour cues within the same experimental situation and across identical stimuli.

As we have already shown that GL can use contour cues for discriminating melodies, we expected a normal advantage of contour-violated over contour-preserved melodies. Contrasting with this efficient use of contour as a melodic feature, we expected him to fail to use scale cues in those melodies. As this latter cue would no longer be available to him, overall GL should perform less well than normals.

Results and Comments

GL obtained 67/96 correct responses (with 44/48 and 23/48 for the “same” and the “different” trials, respectively); his performance was found to be significantly below that of normal controls (mean: 87.5; range: 84–91; $\chi^2 = 12.6; P < 0.001$). Further examination of the data as a function of the melodic cue available in the comparison melody for discrimination disclosed a very different pattern in GL than in controls (see Fig. 7). As predicted, GL did show a contour superiority effect (SD and DD melodies were better differentiated than SS and DS, with 17/24 vs. 7/24, respectively) whereas he did not show the scale violation effect (DS and DD were no better discriminated than SS and SD, but rather showed the opposite trend, with 11/24 vs. 13/24, respectively). In contrast, controls exhibited both effects; they displayed a contour superiority effect (23.0/24 vs. 17.4/24) and a scale violation effect (21.6 vs. 18.8). The effects were found to be valid at the individual level, since each control exhibited these effects. Moreover, the control pattern is identical to the results obtained by Zatorre (1985).

Thus, it appears that GL’s difficulty with this task resides in his failure to exploit scale structure in the melodies. To achieve melodic differentiation, he relied heavily on contour information. It should be remarked, however, that GL’s apparent failure to make contact with a proper musical scale did not prevent him from using interval size information, at least to some extent. Otherwise, he should have failed to differentiate all the SS
and DS melodies, which were not discriminable on a contour basis; he succeeded in differentiating about a third of these contour-preserved melodies. This performance is, however, poor compared to normals and suggests either that interval encoding is deficient in GL or that scale anchoring of intervals is necessary for accurate interval discrimination in a melodic context.

**Experiment 5: Tonal Closure**

The fact that GL failed to use scale information with melodies of a manageable length for his impaired short-term memory supports our initial diagnosis of a tonal loss. This finding encouraged us to re-examine his way of dealing with melodic closure but, this time, with melodies that did not overload his memory capacity. To do so, we used the tone profile technique that is currently the dominant tool for examining the use of tonal encoding in normal listeners. In this paradigm, the listeners hear a musical context followed by a probe tone that scans all the chromatic pitches. The listener’s task is to judge how good the probe tone is as a completion of the context. From these responses, a tone profile is derived, that is, the variation of ratings as a function of the pitch of the probe tone. This profile typically reveals that diatonic tones are preferred over nondiatonic tones and that there is a hierarchy of preference among the diatonic tones: The triad tones are preferred over the nontriad tones, and among the former, the tonic receives the highest rating.
In the present experiment, we used the task of Cuddy and Badertscher (1987) that was adjusted to the testing of young children. This task was particularly appropriate for several reasons. First, one condition, derived from the arrangement of triad tones, requires consideration of only 5 tones, which falls within the memory capacity of GL. In the key of C major, the context pattern corresponds to the notes C-E-C-G (see Fig. 8). This pattern was presented in 3 different keys (C, C#, and D), each being followed by one of the 12 possible chromatic tones as the probe tone and being recorded 4 times in a random order, thus creating 144 trials. Second, musical significance was added to the task by asking subjects to help the experimenter to choose good song endings. Accordingly, for each trial, GL was required to rate whether it sounded “good” or “bad” on a 5-point rating scale. Third, in order to obviate the difficulty of transposing the tone-probe to a different octave (as done in the original study of Krumhansl & Shepard, 1979), all tones were generated with spectral characteristics intended to reduce the salience of the pitch height dimension (these were Shepard tones).

**Results and Comments**

Following Cuddy and Badertscher’s procedure, we asked GL to rate his judgments on a five-point scale (from “good, very sure” to “bad, very sure”). However, he did not use the full rating scale, responding quite confidently “good” or “bad”. Therefore, controls were asked to respond on the same dichotomous response mode.

A first level of analysis indicating tonal encoding of the probe tones is along the diatonic/nondiatonic distinction. Diatonic probe tones should yield more positive responses than nondiatomic tones. This was true for controls, who responded “good ending” for 76.7% of the diatonic tones versus 27.7% for the nondiatomic ones (t_4 = 10.485; P < 0.001). The reverse appeared in GL’s data: He preferred the nondiatomic tones (78%) over the diatonic ones (58%, χ² = 8.29; P < 0.01). This puzzling result

![Diagram](image.png)

**FIG. 8** Example of trials used for the judgments of melodic closure in Experiment 5.
led us to inquire about his strategy. GL’s answer was immediate and well articulated. He said that he was judging the ending according to the fact that a singer usually does not end with a large pitch skip but with a very close and descending pitch. Translated in the present terms, he reported having used pitch proximity and contour.

To verify whether GL did judge the ending according to these 2 nontonal cues, we first asked 2 independent judges to rate the contour of the last interval. In effect, since pitch height is decreased in these sequences, given the use of Shepard tones, we had to assess this subjectively. The probe tones that were originally located at a pitch distance of 10 and 11 chromatic steps above the tonic were in fact judged to be 2 and 1 step below it; yet, the judges described these as ambiguous since both pitches (an octave apart) could be heard. Thus, with these re-ordered tones, and following the usual procedure, the tones were aligned with respect to the key of C, that is, as if the first tone of the triad were always C; thus, the probe tones ran through the chromatic scale from A# to A, with C as the correct tonic note for the profile. The average responses of “good endings” for controls and GL are displayed in Fig. 9.

As can be seen, GL’s “good ending” responses reflect a preference for probe tones that are close in pitch to the last tone of the context (being G; see Fig. 8) and that make a descending interval (from D# to F#) rather than an ascending one (G# and A). The judgments for the lower end do not follow that general pattern; this might be due to an ambiguous pitch percept described earlier. Yet, except for these latter responses, GL’s profile corresponds with his introspective comments and stands in sharp contrast with that of controls’). Controls showed clear differentiation of diatonic over nondiatonic tones, as reflected in their broken profile; however, they did not show clear evidence of tonal hierarchy. They did prefer the triad tones (C, E, and G) over some of the nontriad diatonic tones (like B) but not over others (see for example A, which is as highly rated as G). Thus, only inferences about diatonicism are warranted with the present task. Nevertheless, even at this level, GL does not show the slightest evidence of the normal sensitivity to this factor.

Yet GL’s judgments were not random; they were consistent with the use of nontonal cues of closure. The discovery of his strategy in the present experiment led us to re-examine his responses in our first investigation of tonal closure (see Section 1). It should be recalled that we already noted his performance to be systematic, although being at chance with regard to the expected tonal interpretation of the ending. Moreover, care was taken always to use a descending contour in that task. Thus, if GL was interpreting the same kind of nontonal cues as here, he should have used the pitch distance from the last contextual tone to the probe tone. His responses were re-analysed as function of this particular cue and are pre-
FIG. 9  Tone profiles displayed by GL as well as controls in Experiment 5.

sentenced in Fig. 10. As can be seen, pitch proximity was the cue systematically adopted by GL to judge melodic closure, instead of the more standard use of tonal relatedness.
Experiment 6: Tonal Preference and Advantages

In the previous experiment, we saw that GL failed to exploit tonal cues but relied on nontonal ones for judging the adequacy of melodic endings. In doing so, he readily accepted nondiatonic endings. For GL, then, in contrast to every other subject, tonal music seemed to sound like atonal music. If so, he should not make any difference between the two styles. One way to assess this implication experimentally is to devise a preference task.

Contrary to some aesthetic theories that predict maximum preference for musical excerpts that depart from typicality (e.g. Meyer, 1956), both Cross et al. (1983) and Smith and Melara (1990) have shown that non-musicians as well as musicians prefer musical sequences that are most typical of the tonal idiom. This finding is consistent with another current of experimental research showing that more familiar stimuli are consistently preferred (e.g. Zajonc, 1980). Thus, a preference task might provide a means of collecting more convergent evidence about GL’s lack of tonal sensitivity or his tonal indifference.

Given the knowledge we had already accumulated about GL’s memory capacity and melodic strategies, it was necessary to impose several constraints on the test material. First, each melody should not exceed 6 tones. Second, and more importantly, neither pitch skips nor contour cues should
be available as a basis for aesthetic judgments. Therefore, we used 5-tone melodies that were manipulated by pairs so that one sounded nontonal and the other tonal, whereas contour remained identical and the size of pitch skips equivalent between the members of each pair. Several pilot studies were necessary in order to make sure that the members of each pair were heard as tonal and nontonal with sufficient consistency to construct a preference task. A set of 11 such pairs was so selected (see Fig. 11 for an example). These were presented twice in random order, once with the tonal member as the first melody and once as the second melody. Subjects were required to indicate which one they preferred for each pair.

GL was reluctant to perform the preference task. Consequently, using the same material, we designed a discrimination task, that is both more traditional and less direct than the preference task. We used a task similar to the one developed by Françès, Lhermitte, and Verdy (1973), who showed that tonal conformance of melodies failed to facilitate melody discrimination in aphasic patients. In the present study, we simplified task requirements by using the “same–different” classification. When different, the melodies differed by the last tone, in order for the subjects to accumulate as much evidence as possible about an eventual key common to the two melodies. Half of the trials contained pairs of tonal melodies, which were used in the preference task; and half of the trials contained pairs of the nontonal members. The last tone preserved the contour of the target melody but was modified by three semitones. This was accomplished such that the diatonic structure of the melodies in the tonal trials was respected and that it maintained a departure from such a structure in the nontonal ones (see Fig. 11).

Controls were expected to take advantage of the tonal conformity of the melodies, by displaying superior discrimination of the tonal melodies

![Figure 11](image_url)

**FIG. 11** Examples of trials used in Experiment 6. “A” represents one trial used in the preference task where the first member is more conformed to tonal structure than the second member. “B” and “C” represents the two types of trials derived from the pair “A” to provide tonal and nontonal pairs, respectively, to be differentiated in the discrimination task.
over the nontonal ones. GL was not expected to show such an advantage. In contrast, he might be expected to perform as efficiently as controls on the nontonal trials since the latter would not be discriminated on a tonal basis. However, the latter expectation might be unrealistic, since normals do attempt to assimilate nontonal sequences to tonal ones. For instance, the selection of nontonal sequences was rendered difficult precisely because pilot subjects always tended to assimilate the melodies to a common scale by admitting the occurrence of an accidental or a modulation. We had to force the subjects to use more stringent criteria in their classification of the tonal and nontonal sequences. Nevertheless, mere demonstration of a lack of tonal superiority effect in GL with the discrimination task will allow us to draw direct comparison with the existing literature (i.e. the study of Françès et al., 1973).

GL was presented twice with the same material, with four months elapsing between the two testing periods. The second presentation was motivated by the need to collect response times, in order to allow comparison with the normal controls who were performing at ceiling level. The accuracy measures obtained with GL were collapsed across the two sessions.

Results and Comments

Preference. Out of the 22 pairs, GL chose the tonal one in only 8 cases, which is below chance (of 50%). Normals preferred the tonal melody in 20.2 (range: 18–22) of the 22 trials. Thus, GL’s performance is clearly abnormal. Moreover, GL was very reluctant to perform this preference task, always stating that it did not make any sense. He complained that he heard differences, but that he did not know how to interpret them. His frustration was quite high. Although GL’s preference data are very suggestive, his unwillingness to perform the preference task argues for the need to use either a task in which alternative cues to the tonal ones are available (like in the preceding experiments), or a task that indirectly measures tonal interpretation of the pitches. The discrimination task corresponds to this latter characteristic.

Discrimination. GL obtained 55/80 correct responses (68.8%); he did not perform significantly better on the tonal trials (28/40) than on the nontonal trials (27/40). His performance was far below that of normals who obtained on average 36/40 (90%). Two normal subjects showed a tonality superiority effect whereas the others obtained a perfect score (on average, the group obtained 19 vs. 17/20, for tonal and nontonal trials, respectively). Obviously, GL did not reach normal performance on the nontonal trials. In order to ensure that tonal sequences were easier to
discriminate than nontonal ones, in the context of a very easy task for controls, a more sensitive measure was required. Thus, we measured response times. The tonal R.T. advantage was an average of 132msec in normals; each control demonstrated this effect ($t_{4} = 4.138; P < 0.01$). In contrast, GL showed a nontonal advantage of 46msec. Thus, on neither measure did GL exhibit the normal tonal superiority effect. Therefore, once again, GL failed to show evidence of using tonal scale as a way to organise and retain melodic information. Under these conditions, and when there is no other way to differentiate the melodies except by retaining four interval sizes, his performance is below that of normals. The fact that he performed above chance, however, warrants the conclusion that his lack of sensitivity to tonal structure was not due to a floor effect. Both this latter observation and the robust tonal superiority effect consistently found in normals support the idea that such a task is a sound method for demonstrating a loss of tonal knowledge due to brain damage; and they do so more convincingly than Françès et al.’s (1973) own results.

**Summary of Tonal Encoding Processes**

Altogether, the results obtained in four different experimental settings converge on the idea that GL can no longer use tonal cues as a means of encoding pitch material in melodies. Contour cues and interval cues are still available, but their use does not compensate for his amelodia.

**GENERAL DISCUSSION**

We have documented the case of a patient, GL, who presents auditory atonalia as a consequence of brain damage. This breakdown in auditory processing of melodic patterns occurs in the absence of disturbances in the processing of temporal information and in the presence of accurate encoding of melodic contour and, to some extent, of interval sizes. Contrasting with the relative preservation of these melodic organisation principles, tonal interpretation of melodic sequences was impossible in perception. As this study represents the first attempt to specify the functional locus of atonalia, GL’s results provide a basis for consideration of several issues of theoretical importance: That is, the independence and organisation of tonal processing components within the music system and their potential for explaining various types of musical disorders.

It should be emphasised first that several sources of evidence were considered in order to arrive at the conclusion that GL had lost the procedures enabling him to abstract musical pitch along musical scales when assessed in the auditory modality. In five different experimental settings, involving judgments of melodic closure (Section 1 and Experiment 5), discrimination abilities (Experiments 4 and 6b), and preferences (Experiment 6a), GL’s
results converge on a lack of sensitivity to tonal melodic cues. This absence of tonal sensitivity stands in sharp contrast with his consistent and recurrent reliance on contour and, to some extent, on interval cues for performing the same tasks. GL even used these cues as alternatives to the more conventional tonal criteria in judging melodic closure (Section 1 and Experiment 5). This is an important fact that provides qualitative, and not merely quantitative, support to the notion that GL has lost access to tonal knowledge. Above all, the pattern argues against a general deficit in melodic organisation processes.

Furthermore, the convergence of the results gathered across different tasks supports the robustness of the phenomenon, since it cannot be attributed to the effect of a particular method of measurement or to some variability in behaviour. Finally, GL’s atonalia cannot be easily attributed to his nonmusician background, since each of the control subjects, who were nonmusicians as well, showed sensitivity to the tonal manipulations. Therefore, there are solid grounds for attributing GL’s amelodia to damage in the system encoding melodic intervals in terms of tonal musical scales.

This conclusion supports our claim that tonal knowledge might be subserved by a modular organisation. As we have argued elsewhere in more detail (Peretz & Morais, 1989), tonal encoding of pitch possesses several properties of a module in Fodor’s (1983) sense. First, the tonal system is specific to music (Balzano, 1982; Shepard, 1982; Sloboda, 1985). Second, it appears to mediate perception of pitch in an automatic way, without conscious awareness (Shepard & Jordan, 1984). Third, it seems to operate very early in ontogenic development, around the age of ten months (Cohen, Thorpe, & Trehub, 1987), thus without explicit tutoring. All these properties suggest the existence of a module for tonal encoding of pitch. Modules are also conceived as separate cognitive subsystems that are associated with specific, identifiable neural systems. Damage to these distinct neural circuitries entails the potential to exhibit “specific breakdown patterns.” To the extent that access to tonal knowledge was indeed selectively disrupted by brain damage in GL, the present study has verified still another modular property that tonal encoding of pitch appears to possess.

The issue of selectivity—or specific breakdown pattern—requires, however, further elaboration. In all the experimental situations where an interval-based representation of the melody was required to perform the task, such as with contour-preserved melodies (Experiments 3, 4, and 6b), GL exhibited some residual capacity to accomplish the task. In contrast,

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3This specificity is, however, not restricted to a particular style or idiom, as in the Western tonal system; it refers to some abstract principles that are instantiated in the tonal system but that essentially cut across styles and time. It is an analogous claim, in essence, to the less controversial notion that modules exist that are devoted to the understanding of speech in general, not just of French in particular.
in all the experimental situations where a tonal representation was either required (Section 1; Experiments 5 and 6a) or advantageous (Experiments 4 and 6b), GL did not exhibit the slightest indication of residual knowledge at that level. Thus, GL displayed partial success with interval-based procedures and total failure with their tonal transformations for identical melodic sequences. Assuming that computation of these two kinds of information is equally difficult, this discrepancy in the manifestations of impairment is consistent with the existence of two independent, but possibly interacting, components, thus empirically supporting the distinction made theoretically in the Introduction. If interval sizes were the input code and tonal transformations were the output code of a single module or network, as conceptualised by Bharucha (1987), degradation at any one level should entail degradation at the other level. The amount of degradation should not necessarily be equal, as suggested by a recent study of Tramo, Bharucha, and Musiek (1990), but would probably not follow the degraded versus abolished character of GL’s behaviour.

The problem with this issue is that the existence of a dual code for representing pitch information in melodic sequences is relatively easy to conceptualise, but problematic to tease apart in a patient who is impaired at this level. The distinction is blurred because one of the fundamental roles of tonal encoding of pitch is precisely to allow accurate encoding and retention of pitch intervals. Just as the encoding of speech sounds crucially depends on the mapping of continuous variable sounds onto a restricted number of phonemic categories, the encoding of musical pitch depends on the mapping of the frequency continuum to an underlying discrete set of categories, which are provided by the musical scales. Losing this framework may result in poor interval discrimination abilities, particularly in melodic sequences wherein interfering pitch material exacerbates the well-known limitation of the human perceptual system to deal with a continuous variable. As a consequence, GL’s deficiency in dealing with melodic intervals might well be the result rather than the cause of his tonal breakdown pattern.

Several indications are consistent with the idea that the accuracy of interval representation in a melodic context is dependent upon proper scale categorisation. First, GL did show evidence on several different occasions of accurate pitch encoding abilities and of normal interaction within an auditory short-term memory system dedicated to retain pitch information along a single frequency continuum. He easily discriminated two pitches, even a semitone apart, when these were presented in isolation (see Section 1). He displayed normal facilitation through repetition and interference through proximity in an interfering pitch recognition task (Experiment 1); and he spontaneously used pitch interval sizes as a melodic organisation principle (Experiment 5 and, probably, Experiment 2). Taken together,
these findings raise some doubts as to whether GL’s primary deficit lies at the level of pitch interval encoding. Rather, the results suggest that his deficiency in using interval size information in a melodic context lies at a higher level, either in the procedures that transform interval sizes into a scalar code (i.e. an access problem or a translation failure) or at the level where this operation is realised (i.e. a tonal disruption). In this account, tonal encoding of pitch is considered to be central to melody organisation; thus an impairment at that level will result in a poor record of melodies. This is a strong claim. For example, it has far-reaching implications for the way the average listener retains contemporary atonal music. The goal of future research should therefore aim at assessing this notion.

The notion that an impairment at the level of tonal encoding will lead to a poor record of melodies is, however, consistent with the proposal that scale categorisation is essential for short-term memory of pitch, as considered in the Introduction. In fact, one major role attributed to the universal use of scales in music is that they respond to the need of the human limited memory capacity (Dowling, 1978; Krumhansl & Shepard, 1979). Even though the commonly used scales differ somewhat from culture to culture, most have common properties. Most musical scales make use of pitches an octave apart and are organised around five to seven focal pitches (Dowling, 1978; 1982). The prevailing view is that scales derive from a need to reduce the information content of melodies within psychologically acceptable limits, i.e. the magic number seven (Miller, 1956). In accordance with this notion, Françèes et al. found a strong association between amelodia and melodic span. These authors noted that their patients failed to deal with melodies of more than four tones, whereas normals did well with longer melodies. Similar short-term memory limitations were also found in GL. Although he was able to compensate for this difficulty to some extent by using contour cues (e.g. the span task used in Section 1) and chunking strategies (Experiment 2), GL had marked difficulties when required to compare melodies containing more than six tones, or two melodic motifs (Experiment 3), and showed heightened susceptibility to pitch interference (Experiment 1). However, this short-term deficit appeared to be restricted to pitch material, since GL did not encounter any difficulties in dealing with rhythmic sequences (Section 1).

One conservative interpretation of these findings is that short-term memory deficits are unrelated to atonalia. These deficits would arise because brain lesions are relatively large and, thus, could have affected more than one processing component. Yet, as argued by Caramazza (1986), the interpretation of an association depends crucially on the model to which one refers. The present view departs from the assumption that memory is a distinct faculty on its own. Rather short-term memory is conceived of as a by-product of information processing, particularly for
scale encoding of pitch. Thus, we favour the notion that short-term memory and atonalia arise from a single impairment that precludes access to a more durable trace of melodic pitches. Accordingly, the present set of results might be taken as the first demonstration of a direct relationship between scale information and memory span for musical pitch.

In summary, the present case study supports Françès et al.'s (1973) contention that amelodia can be the result of damage to tonal knowledge or to its access. What the present case adds to this earlier finding is more information about the experimental settings that are appropriate to shed light on this disorder. In this study, we relied heavily on the recent advances made in the study of normal cognition. Reciprocally, we wish to see GL's data not so much as detailed grounds for testing these theories but rather as indicators to aspects of music behaviour, such as singing, for which, as yet, no well-developed theory and methods exist.

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REFERENCE NOTES

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