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Receptive amusia: temporal auditory processing deficit in a professional musician following a left temporo-parietal lesion

Marie Di Pietro*, Marina Laganaro, Béatrice Leemann, Armin Schnider

Service de Rééducation, Hôpital Cantonal Universitaire, 26, Av. de Beau-Séjour, CH-1211 Genève 14, Switzerland

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Abstract

This study examined the musical processing in a professional musician who suffered from amusia after a left temporo-parietal stroke. The patient showed preserved metric judgement and normal performance in all aspects of melodic processing. By contrast, he lost the ability to discriminate or reproduce rhythms. Arrhythmia was only observed in the auditory modality: discrimination of auditorily presented rhythms was severely impaired, whereas performance was normal in the visual modality. Moreover, a length effect was observed in discrimination of rhythm, while this was not the case for melody discrimination. The arrhythmia could not be explained by low-level auditory processing impairments such as interval and length discrimination and the impairment was limited to auditory input, since the patient produced correct rhythmic patterns from a musical score. Since rhythm processing was selectively disturbed in the auditory modality, the arrhythmia cannot be attributed to a impairment of supra-modal temporal processing. Rather, our findings suggest modality-specific encoding of musical temporal information. Besides, it is proposed that the processing of auditory rhythmic sequences involves a specific left hemispheric temporal buffer.

Keywords: Rhythm processing; Amusia; Music perception

1. Introduction

Melody and rhythm are the two primary dimensions of music. Melody refers to pitch variations, rhythm refers to temporal variations. Both theoretically and empirically, melody and rhythm tend to be treated separately. Case studies of patients with brain damage suggest that rhythm and melody are processed by separate modules, as supported by selective impairment of one, but not the other, musical component (Assal, 1973; Botez & Wertheim, 1959; Brust, 1980; Mavlov, 1980; Peretz, 1985). The double dissociation between rhythm and melody discrimination has already been observed in group studies (Ayotte, Peretz, Rousseau, Bard, & Bojanowski, 2000; Liégeois-Chauvel, Peretz, Babaï, Laguitton, & Chauvel, 1998; Peretz, 1990). Similarly, selective disorders of melodic discrimination have been documented in prior studies (e.g. Peretz, Kolinsky, Tramo, Labrecque, Hublet, Demeurisse, & Belleville, 1994; Piccirilli, Sciarma, & Luzzi, 2000).

Cognitive models further divide the components of music processing (Peretz & Coltheart, 2003; Peretz & Kolinsky, 1993). In the melodic dimension, two features have been identified: interval (distance in pitch between two successive notes) and melodic contour (the overall trajectory of pitch). In the temporal dimension, a distinction has been proposed between rhythm (the relative duration of units) and meter (the periodic alternation between strong and weak beats). These distinctions are partly based on the assumption that some features of melodic and temporal processing require global processing (melodic contour and meter), whereas the other features depend on local processing (interval and rhythm) (Bever & Chiarello, 1974; Peretz, 1985; Peretz & Babaï, 1992; Peretz & Morais, 1993).

This distinction between global and local processing seems to reflect differential involvement of the cerebral hemispheres. The hemispheric contribution to music perception has been investigated by neuropsychological, functional imaging and neuroanatomical studies. An influent study by Peretz (1990) with unilateral brain-damaged non-musician patients, showed that left temporal damage disrupts processing of local melodic features (interval) leaving global processing (melodic contour) intact, while right temporal damage results in the inverse pattern. In contrast, both left and right hemispheric lesions disrupted local temporal processing (rhythm discrimination). A PET study on music perception by healthy subjects (Patel, Peretz, Tramo, &

* Corresponding author. Tel.: +41-22-382-36-43; fax: +41-22-382-83-38.
E-mail address: marie.dipietro@hcuge.ch (M. Di Pietro).

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Labreque, 1998) demonstrated the involvement of the left inferior Broca's area for rhythm tasks. However, a recent study using functional transcranial Doppler sonography with musicians and neophyte participants, failed to confirm laterality-effect for rhythm processing (Evers, Dannert, Rödding, Rötter, & Ringelstein, 1999). Neuroanatomical studies, too, did not allow to precisely delineate neural regions involved in rhythm processing. Liégeois-Chauvel et al. (1998) confirmed the dissociation between rhythm and meter. They described the deleterious impact of a lesion in the left or the right anterior part of the superior temporal gyrus for metric processing. By contrast, rhythm was spared in all subjects. Alcock, Wade, Anslow and Passingham (2000) tested left- and right-hemisphere-damaged patients, and found that rhythm discrimination was affected by a left hemispheric lesion. It has also been suggested, based on non-musician patients with unilateral lesions, that the right-temporal lobe might preferentially process auditory rhythms (Penhune, Zattore, & Feindel, 1999). In summary, the cerebral asymmetry found for the melodic dimension has not been replicated in rhythm perception.

An important factor influencing the hemispheric specialisation in music processing is the musical experience of the subjects. Bever and Chiarello (1974) showed that subjects with musical expertise present a left hemisphere dominance (right ear advantage for musicians in a melody recognition task) for musical processing. This difference between musicians and non-musicians has been recently confirmed in a morphological and neurophysiological study by Schneider, Scherg, Dosch, Specht, Gutschalk, & Rupp (2002). Results indicated neurophysiological differences between musicians and non musicians while presented with simple tonal stimuli. These differences in levels of musical aptitude were found to correspond with morphological brain differences in Heschl's gyrus.

As regards rhythm impairments, Wertheim and Botez (1961) described a professional violinist, who failed to identify and imitate heard rhythms following a left hemispheric stroke. By contrast, he was better at writing notes for rhythm than for pitch. In addition to arrhythmia, the patient had other components of amusia, resulting in a more global music impairment. Polk and Kertesz (1993) reported two case studies of musicians with probable Alzheimer disease. One patient with left cortical atrophy presented a total loss of the ability to repeat simple acoustic rhythmic patterns, which contrasted with normal spontaneous production of rhythms and intact melodic perception. The second patient, suffering from a primarily right posterior cortical atrophy, presented the reverse profile. He could repeat the rhythms, but was unable to produce a regular beat. However, the arrhythmia in the first case was associated with musical alexia and agraphia, and was also accompanied by a global decline of cognitive functions and global aphasia. One of the most relevant studies of arrhythmia in a professional musician was reported by Mavlov (1980). Following a left posterior parietal lesion, a violinist and music teacher failed to discriminate and reproduce rhythmic patterns in the auditory, visual, and tactile modality. The rhythm impairment contrasted with a preserved ability to recognise and produce pitches.

Thus, pure cases of arrhythmia in professional musicians are rare and offer miscellaneous manifestations of rhythm deficits. In some cases of amateur musicians, disturbance to regulate rhythmic output has been suggested (Fries & Swihart, 1990; Wilson, Pressing, & Wales, 2002). In another case (Mavlov, 1980), the rhythm impairment in a professional musician has been interpreted as a supra-modal defect of rhythm processing.

In the present study, we describe a professional musician showing a selective impairment of rhythm processing limited to the auditory modality, suggesting that rhythm processing reflects the involvement of modality-specific temporal processors.

2. Case description

A 48-year-old, right handed professional baritone (DL) with 14 years of musical education had suffered a left parieto-temporal infarct 4 months before the start of this study. He had not been working as a musician for 5 years because of vocal cord injury. He had no treatment at the time of hospitalisation. On admission, no motor or visual impairments were noted. The patient was well oriented, showed good insight into his difficulties, and was independent in all daily activities.

The patient soon complained of difficulties with the perception of music. He described his altered feelings when listening to music as follows: "Music does not sound right to me .... Music is here but I am missing something. ... When I am listening to a piece of music, I am feeling lost .... Space is all right but not time .... There is something wrong with time because I do not follow rhythm as before. You know, when I hear music, suddenly, I am too late, I loose the rhythm; everything is a bit too late. I don't know what is exactly going wrong, but I think I am missing something with time".

The patient had reported no difficulty with recognising tunes that had previously been familiar to him. Music still affected him emotionally, but he was reluctant to listen to music because of his altered perception.

2.1. Lesion localisation

Fig. 1(a) and (b) illustrate the distribution of the left ischemic lesion. The infarct involves the superior temporal gyrus, the posterior part of the middle temporal gyrus, and the inferior parietal lobule (areas 19, 22, 37, 35 and 40).

2.2. Neuropsychological assessment (Table 1)

A detailed neuropsychological evaluation was conducted 2 months after the stroke. DL reported difficulty with speech

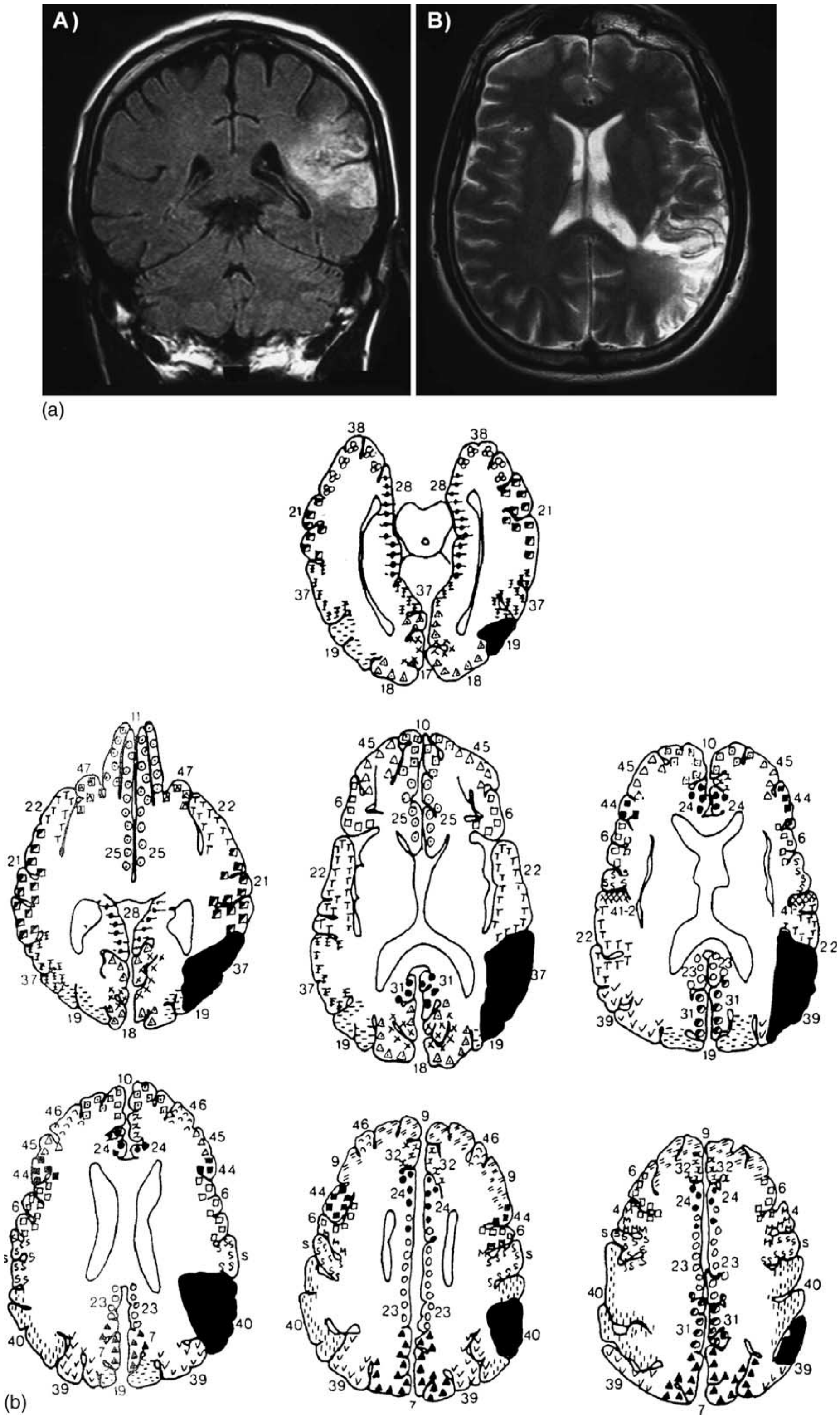

Fig. 1. (a) Axial and coronal slices from the patient's MRI 1 month post-stroke. The scan shows a left temporo-parietal infarct in the territory of the superior temporal gyrus, the posterior part of the middle temporal gyrus and the inferior parietal lobe. (b) Axial templates with cytoarchitectonic marking (Damasio and Damasio, 1989) suggest that areas 19, 22, 37, 39 and 40 are involved.

Table 1
Neuropsychological assessment

	DL raw	Impaired (✓)
Language examination		
Boston naming test	30/36	✓
Boston diagnostic aphasia examination (Mazaux & Orgogozo, 1981)		
Repetition		
Words	10/10	
Phrases	11/16	✓
Verbal fluency (animals)	24	
Oral reading		
Words	28/30	
Phrases	7/10	✓
Reading comprehension		
Written spelling Batterie cognitive d'examen de l'écriture (De Partz, 1994)	31/40	✓
Auditory comprehension		
Modified token test (De Renzi & Faglioni, 1978)	31/36	✓
Visual-constructive functions		
Copy of Rey–Osterrieth complex figure (Osterrieth, 1944)	36	
Visual perception		
Visual agnosia test (Agniel et al., 1992)	42/42	
Memory tests		
Verbal span	4	✓
Rey auditory verbal learning test (Rey, 1958a,b)	60	
Rey–Osterrieth complex figure (Osterrieth, 1944)	24	
Executive functions		
Figural fluency (Regard, Strauss, & Knapp, 1982)	22	
Attention test		
Tests d'évaluation de l'attention (TEA) (Zimmermann & Fimm, 1994)		
Divided attention	66	
Intellectual processes		
Progressive matrices short version (Raven, Court, & Raven, 1998)	23	

production and complained of word-finding difficulties. Language examination showed fluent, grammatical oral production with residual naming difficulties. Oral reading and repetition of long sentences showed phonemic paraphasias. Oral and written comprehension were well preserved, except for complex material. In written spelling, the patient produced letter paragraphias with a word length effect. Number processing assessment revealed mild difficulties to read and write numbers (phonemic paraphasias and number substitutions). Divisions were carried out slowly, the patient saying he could not remember how to proceed. In other cognitive domains, the patient's performance was normal. There was no buccofacial or limb apraxia. No neglect was present (Gauthier, Dehaut, & Joanette, 1989).

In summary, neuropsychological examination was not normal, but revealed mild deficits in language (moderate conduction aphasia), in number processing (mild alexic/agraphic and anarithmetic acalculia), and in memory (defective verbal memory span).

3. Experimental methods and results

A group of 10 healthy participants (aged 25–40 years), with no history of neurological disease served as controls for the tasks where DL demonstrated particular difficulties. All had university education and were non-musicians, i.e., they had moderate to no training and/or practice in music. The patient and controls gave informed consent to participate in this study.

3.1. Evaluation of basic musical abilities

Perceptive and productive musical functions were assessed with a musical battery that evaluated different aspects of music processing.

3.1.1. Music-production tasks (Table 2)

The patient's ability to sing a known melody by heart was examined. He was instructed to sing from memory a bass portion of Mozart's Requiem. His spontaneous singing was easily recognisable, and neither rhythm nor melodic impairments were present.

To test music writing, the patient was first asked to write through dictation individual notes ($n = 10$) on the treble and the bass clefs. Secondly, the patient listened to a sequence of notes and was asked to write out the corresponding score. He performed 100% in these two tasks. Finally, the patient

Table 2
Patient's performance (percentage) in the musical abilities battery

Subtest	*n*	Score (%)
Production tasks		
Writing musical scores	40	98 for note pitch
Music reading		
Notes naming	32	100
Notes singing	32	100
Singing a known melody	1	Preserved
Melody reproduction	10	100
Melody production from score	10	100
Rhythm reproduction	20	40
Rhythm production from score	20	100
Lower-level auditory processing		
Discrimination of timbre	10	100
Discrimination of intensity	10	100
Discrimination of pitch	20	100
Discrimination of length	20	100
Discrimination of interval	20	100
Identification of musical instruments	10	100
Recognition of musical pieces	10	100

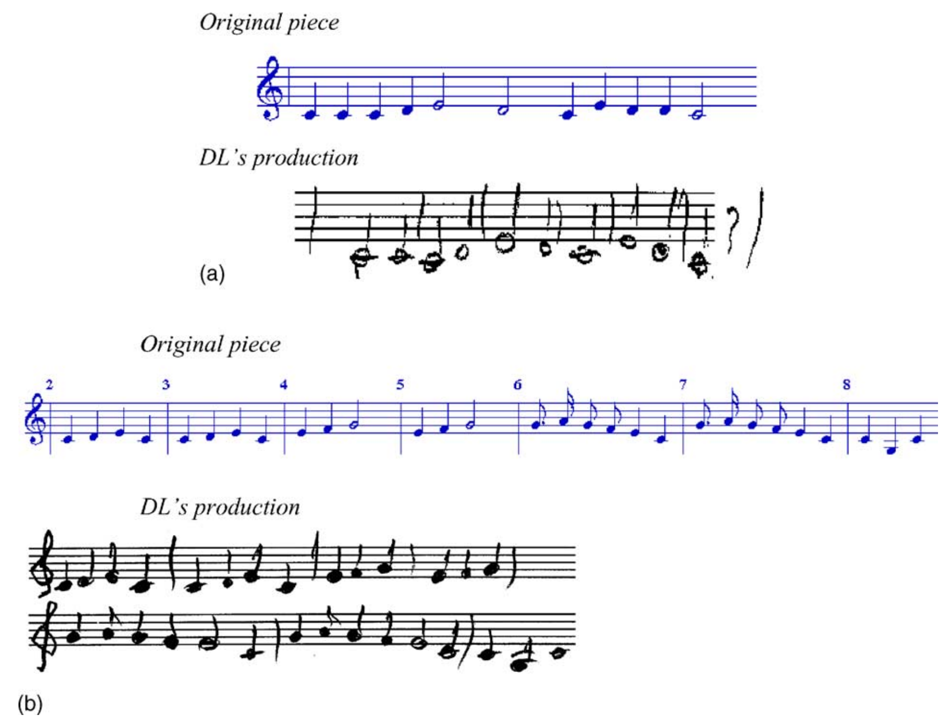

Fig. 2. (a) Writing of a musical piece ("Au Clair de La Lune"). (b) Writing of a musical piece ("Frère Jacques").

listened to two pieces (popular children's songs: "Au Clair de la Lune", "Frère Jacques") played on a single instrument and was instructed to write out the tune on a blank stave. The two pieces had to be written on the treble clef. Each piece was played as many times as requested by the patient. Although the pitch was correctly written (98%) for the two pieces, the derangement of rhythm was remarkable. In the first piece, the patient omitted one note and substituted all quarter notes by whole notes, resulting in a non-rhythmic sequence (Fig. 2a). For the second piece, the pattern of errors was similar (Fig. 2b). DL made several substitutions (two whole notes substituted by two quarter notes; two eighth dotted notes by two quarter notes; two 16th notes by two eight notes; two eighth notes by two quarter notes; two quarter notes by two half notes).

Note that the patient mentioned that he was skilled in writing musical notation before stroke, and that he had a conductor formation.

To test his ability to read music, the patient was asked on two different sessions to name and to sing written notes displayed on single staves, where the clef symbol was printed. Four measures were in F clef and four in G clef, for a total of 32 notes. Naming and singing written notes was intact, but the patient had lost his absolute pitch (according to the patient, he had absolute pitch before the stroke). Although the melody was intact, the temporal pattern of some notes was slightly distorted.

Finally, three tests of theoretical musical knowledge (solfeggio) were administered. In the first task, aiming to assess knowledge of accidentals (natural, sharp and flat signs), the patient was presented with a series of 10 written note pitches with accidentals that he had to organise from low to high-pitched notes according to the accidentals. The second test was a note value equality task, in which the patient was asked to create durational values equalities between written notes. Finally, in a measure completion task, the patient was asked to write missing durational values on ten measures. On all these theoretical tasks, the patient scored 100% correct.

3.1.2. Music-perception tasks (Table 2)

For the music-perception tasks, stimuli were presented in pseudo-random order. On each trial, the patient indicated his choice by pointing to one of two screen buttons ("same" and "different").

3.1.2.1. Lower-level auditory assessment.

Discrimination of timbre and intensity. Timbre and intensity discrimination was assessed by the subtests of the Montréal-Toulouse auditory agnosia battery (Agniel, Joanette, Doyon, & Duchein, 1992).

Pitch discrimination. Each trial was composed of two musical notes, separated by a 1000 ms ISI. The frequency difference between notes (in half the pairs) varied from a semitone to a tone.

Durational value discrimination. Pairs of notes were presented—separated by a 1000 ms ISI. In half of the trials, the length of one note was altered. The length of the notes varied from 250, 500, and 1000 ms.

Interval discrimination. Each trial was composed of three notes lasting 445 ms, which were separated either by two identical or different silent intervals (varying from a 16th to a quarter fraction of time).

The patient performed all tasks perfectly (100% correct).

3.1.2.2. Musical instruments and musical pieces recognition. Short melodies were played with 10 different individual instruments, and the patient was asked to identify the instrument by pointing to the corresponding picture from among four pictures. To test recognition of classical pieces of music, the patient was asked to name the composer of 10 pieces played to him (e.g. Don Giovanni—Mozart; Tosca—Puccini; Stabat Mater—Vivaldi). The patient's performance was normal in these tasks, as he correctly recognised all musical instruments and indicated the composer of classical music in 10 out of 10 trials.

3.1.3. Musical auditory perception tasks: local and global processing (Table 3)

The material was designed according to the description of Peretz (1990); Schuppert, Münte, Wieringa, & Altenmüller (2000), and represents globally and locally altered melodies. Except for the metric task, twenty pairs of musical sequences served as stimuli, and the patient had to make a "same-different" classification. On each trial, the patient was instructed to judge whether two sequences, separated by a constant ISI (2000 ms), were the same. Each trial consisted of a warning signal ("attention") and a target sequence, followed by a comparison sequence. For the metric task, the patient was instructed that he would have to discriminate between waltzes and marches in each musical excerpt he would be hearing. In this task, the number of correct answers was considered. The other subtests were scored as percent correct answers. For all subtests, feedback was provided on the computer screen ("right", "wrong") only on the two practice trials.

Table 3
Patient's performance (in percentage) in the auditory discrimination and production tasks

Subtests	*n*	DL (%)	Controls (%)
Auditory discrimination			
Identification of metre	10	100	
Discrimination of rhythm	20	50	87 (range 70–100)
Discrimination of contour	20	100	
Discrimination of interval	20	100	
Production			
Rhythm reproduction	20	40	
Melody reproduction	10	100	
Rhythm production from score	20	100	
Melody production from score	10	100	

3.1.3.1. Metric-classification task. Ten music sequences (five waltzes and five marches) of 15 s were auditorily presented. The patient identified 10 out of 10 music sequences.

3.1.3.2. Rhythm-discrimination task (Fig. 3(a)). The sequences were pairs of musical sequences of 4–5 notes long, and were made up of short and long tones (of 112, 225, 450, 675, 900 and 1350 ms) of fixed pitch. DL's performance in this task was at chance (50%) and significantly inferior to the control group of non-musicians (significance test: Crawford & Howell, 1998: $t = -2.3$, $P < 0.05$).

3.1.3.3. Contour-discrimination task (Fig. 3(b)). The musical pair sequences consisted of 3 or 4 bar each (either in

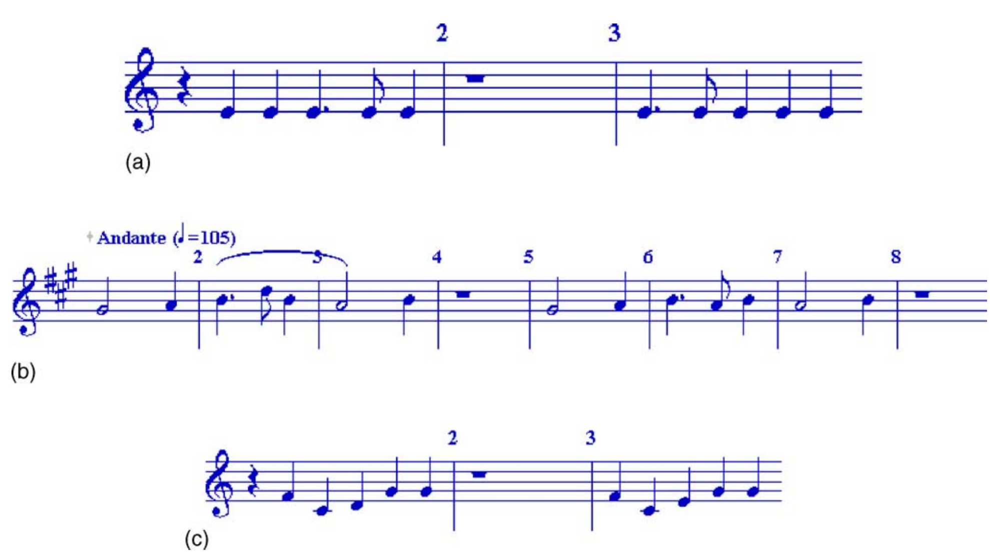

Fig. 3. (a) Rhythm-discrimination task. Example of the musical stimuli on which DL failed (temporal pattern). (b) Contour-discrimination task. (c) Interval-discrimination task. Example of the musical stimuli on which DL succeeded (pitch pattern).

3/4 or 2/4 m). The second sequence in each pair was manipulated by altering the pitch of one note in the 10 original sequences in order to change its contour. The patient discriminated 20 out of 20 melodies with contour change.

3.1.3.4. Interval-discrimination task (Fig. 3(c)). The manipulation applied to the second pair of 10 original sequences consisted of modifying one note without modifying the melodic contour. The melody sequences contained tones of equal duration. The pairs of sequences were comparable in length to the rhythm discrimination task. The patient correctly discriminated 20 out of 20 melodies with interval change.

3.1.4. Rhythm and melody reproduction tasks (Table 3)

3.1.4.1. Auditory reproduction tasks. The patient was asked to reproduce rhythmic sequences and to sing melodies. These two tasks were administrated in two separate sessions. There were 10 stimuli in the melody reproduction task, which corresponded to 2 bar melodies taken from the interval-discrimination task. The rhythm reproduction task consisted of 20 stimuli taken from Fries and Swihart (1990). In total, the patient correctly repeated all 10 melodies he had listened to, but he reproduced only eight rhythms correctly out of 20 trials. There was an obvious difficulty with the rhythm task, and the patient abandoned some sequences during the realisation.

3.1.4.2. Production from a musical score. The patient was asked to sing written notes, and to produce a rhythm from musical scores, which consisted of either melodic variation (fixed durational values) or temporal variation (constant pitch). The scores were the same as those of the reproduction task (see above). The patient could produce (tap on a table, and sing) rhythmic and melodic sequences from a musical score without errors.

Material and procedures. In tasks requiring oral or written production of musical components, scores were expressed as the total number of correctly produced components (notes and intervals). In recognition tasks, the number of correct answers was considered. Musical theoretical knowledge was expressed as number of correct or incorrect responses. Vocal output was recorded and scored by a professional musician. The rhythm production task was scored independently by two raters and a professional musician.

Stimuli of the lower-level auditory assessment and the musical auditory perception tasks were computer-generated with a music composition software and played in organ sound at a fixed tempo of 120. Stimuli were presented binaurally, by means of headphones (SONY MDR-CD480). They were generated by a microcomputer PC which recorded the responses. Each trial was presented in pseudo-random order and saved as an individual file.

4. Specific rhythm perception assessment

The assessments described below were conducted to determine the nature of the patient's rhythm impairment. The same group of normal participants served as controls.

4.1. Discrimination of visual rhythmic stimuli

In a previous study, arrhythmia in a professional musician was explained by a supra-modal rhythmic defect (Mavlov, 1980). We therefore assessed the patient's ability to discriminate visual rhythms and compared his performance in this task with the performance in auditory rhythm discrimination.

4.1.1. Stimuli

The visual rhythmic sequences were generated from the 20 auditory discrimination rhythmic pairs (rhythm discrimination task). The stimuli used in this experiment were 4–5-element visual rhythmic patterns composed of short (250 ms), medium (500 ms) and long (950 ms) elements (yellow squares of 9 cm). The squares appeared sequentially in the center of a PC computer monitor (HP). On each trial, the subject was presented with a pair of sequences separated by a 2000 ms ISI and a visual cue ("2"), and he had to decide whether the visual rhythmic sequences, were the same or different.

4.1.2. Results

Table 4 (a) summarises the results. The patient gave 19 correct answers in 20 trials, which corresponds to the controls' performance, and contrasts with his performance in auditory rhythm discrimination (50%).

Table 4

	(*n*=)	Patient (%)	Controls (%)
(a) Percent correct answers in the visual-rhythm discrimination tasks			
	(20)	95	85
(b) Percent correct answers for short and long stimuli in the rhythm discrimination task and the interval discrimination task			
Stimuli			
Rhythm discrimination			
Short	(20)	80	97 (range 90–100)
Long	(20)	65	92 (range 80–100)
Interval discrimination			
Short	(20)	100	
Long	(20)	90	
(c) Percent correct answers in the auditory-visual matching task under on-line and off-line conditions			
Condition			
On-line	(20)	95	
Off-line	(20)	75	

4.2. Length effect on auditory discrimination

Clinical observations, the patient's complaints about rhythm perception, and the limited verbal memory span, suggest that DL's impairment of auditory rhythmic discrimination could be explained by a limited memory span. In order to test this hypothesis, we studied the effect of stimulus length in DL's auditory discrimination performance for rhythmic and for melodic sequences.

4.2.1. Stimuli

Auditory rhythmic sequences were generated from the 20 auditory rhythmic pairs in the auditory discrimination rhythm task. Two subsets of 20 pairs were created: one with short pair sequences (4–5 notes), and one with long pair sequences (6–7 notes).

Auditory melodic sequences were generated from the 20 pair sequences in the interval-discrimination task. Two subsets of 20 pairs were created: one with short pair sequences (4–5 notes), and one with long pair sequences (6–7 notes).

This was a "same-different" task. The two sequences were separated by a constant ISI (2000 ms).

4.2.2. Results

Table 4 (b) summarises the results. The patient's performance was significantly inferior to the controls' performance for both subsets in the rhythmic condition (short stimuli: $t = -3.5$, $P < 0.01$; long stimuli: $t = -2.79$, $P < 0.05$). A length effect was observed in the auditory rhythmic discrimination task: the patient encountered more marked difficulties with the long subset (65% correct), as compared to the short one (80%). This decrease of performance for long stimuli was not observed in the melodic condition (interval discrimination task), where DL performed $\geq$ 90% in both conditions.

4.3. On-line versus off-line effect: auditory-visual matching

The previous experiment showed impaired discrimination for auditory rhythms with long musical sequences. In order to further assess differences in performance due to memory demands, we asked DL to match heard and written rhythmic sequences in two conditions ("on-line" and "off-line").

4.3.1. Stimuli

The patient listened to a rhythmic sequence and had to decide (oral response) whether the sequence heard corresponded to the rhythmic sequence written on a musical score. There were 20 trials in this task. The stimuli used were identical to those used in the rhythm reproduction task. The experiment was run twice on two conditions. In the "on-line" condition, the patient looked at the musical scores while listening to the auditory sequence. Briefly afterwards, the task was run again, but the score was presented only after the auditory presentation of the rhythmic sequence ("off-line" condition).

Table 4 (c) summarises the results. On-line auditory-visual matching was markedly better than off-line auditory-visual matching.

In summary, the patient's impairment appears to be limited to the auditory modality. Visual rhythm discrimination was performed flawlessly. In contrast, DL performed below controls' range in the short version of the auditory rhythmic tasks. A length effect was observed on rhythm discrimination only: performance in this task decreased with longer stimuli, while no performance decrease was observed in the interval discrimination task. DL's performance in auditory-visual matching showed a difference between on-line and off-line conditions, which suggest a difficulty to retain the musical rhythmic pattern in a memory buffer.

5. Discussion

The aim of the present study was to investigate the music processing impairment in a professional musician after a left hemisphere lesion. To our knowledge, this case study represents the first observation of a selective impairment in auditory rhythm discrimination in a single-case study.

To summarise the main findings, the patient exhibited normal recognition of musical instruments. He succeeded in singing and reading music, and musical theoretical knowledge was normal. The reproduction of a melody heard was normal, and DL correctly sang a melody from a score. The patient was able to process local (pitch interval) and global (contour) melodic features. By contrast, he failed to write down the rhythmic component of heard music, and presented significant difficulties in tasks evaluating rhythm discrimination and reproduction. The rhythm impairment could not be explained by an impairment in the ability to make a rhythmic motor response, as the patient showed preserved ability to tap rhythms from visual input (musical score). DL's recognition of familiar melodies was unimpaired. This observation suggests that a deficit in perception of rhythmic patterns can occur without associated impairment of melody recognition. Recognition of music has been studied in healthy subjects (Hébert & Peretz, 1997). These authors assume that the pitch structure is the most informative code to access long-term memory for music. DL has a selective deficit in discriminating rhythms, but he recognises music without difficulty. His pattern of deficit is therefore consistent with the assumption that rhythm is a parameter less critical than melody for the recognition of familiar music.

The patient's performance in tasks probing temporal processing showed a spared attribution of meter judgement, in presence of disrupted rhythmic discrimination. This profile of disturbances reinforces the dissociation already suggested between local (rhythm) and global (meter) temporal processings (Liégeois-Chauvel et al., 1998; Peretz, 1990). The fact that rhythm can be selectively impaired suggests that the main components of music's temporal structure do not only require specific processing channels, but are also subserved by distinct neural systems that can be selectively disturbed after brain damage.

The patient's particular impairment differs from the rhythm impairments previously described in professional musicians (Polk & Kertesz, 1993; Wertheim & Botez, 1961) in that DL presents a selective impairment in auditory rhythm discrimination. Mavlov (1980) reported a patient with a rhythmic disorder in discrimination and production. Investigation of his difficulties revealed a rhythm discrimination deficit in the auditory, and visual modalities. The author interpreted the arrhythmia resulting from a supra-modal rhythmic disorder. In contrast, DL showed impaired discrimination of auditory, but not visual rhythms. He also was able to reproduce rhythmic sequences from visual input. According to Peretz and Coltheart's (2003) modular model of music processing, our results suggest that rhythmic procedures and representations are intact but access to it from acoustic input is no more accessible after the left hemispheric lesion. Moreover, the dissociation between the visual and auditory rhythm processing strongly supports the presence of a modality-specific encoding of rhythms which may have a distinct neural code from visual rhythm. This result is consistent with a number of findings suggesting that each modality is represented in its own code (proprietary code hypothesis) (Collier & Logan, 2000; Penhune et al., 1999).

Another factor which should be considered in interpreting the present results is the fact that the patient was more impaired on longer rhythmic sequences, compatible with a decreased memory span. A similar observation was made in an auditory-visual rhythm matching task when a memory demand was added (off-line condition). DL was however not impaired in the melodic condition, even for the discrimination of long sequences, indicating that he was able to adequately retain an accurate representation of the melodic dimension of the auditory stimuli. Thus, both the length effect in rhythm discrimination, and the difference between the on-line and off-line rhythm matching task, appear to be the result of the patient's specific failure to retain a representation of auditory rhythmic stimuli in working memory. This finding is consistent with a previous study on patients with temporal lobe removals, suggesting that working memory plays a role in the retention of an accurate auditory representation of rhythmic sequences (Penhune et al., 1999). It remains unresolved whether or not the processing of auditory rhythmic patterns in working memory represents a distinct module, separate from verbal short-term memory.

The patient's relatively large brain lesion precludes precise analysis of the brain systems involved in rhythm perception. Nonetheless, the lesion includes the superior temporal gyrus of the left hemisphere, known to be involved in music processing (Liégeois-Chauvel et al., 1998; Peretz, Belleville, & Fontaine, 1997; Peretz et al., 1994). This left-hemisphere localisation is consistent both with the functional imaging data demonstrating a left hemispheric activation for rhythm tasks (Platel et al., 1997), and findings which failed to confirm laterality-effects for rhythm processing (Evers et al., 1999). An interpretation of this apparently conflicting data is the notion that musicians and non-musicians might have different strategies in music processing, and that musically competent subjects would adopt musical processing strategies involving the left hemisphere (Bever & Chiarello, 1974; Peretz & Morais, 1980). The observation of DL's disturbances reinforces the suggested contribution of left hemisphere structures to analytical levels of musical perception.

In conclusion, this case report completes the predicted double dissociation between auditory rhythm and melody discrimination processings. Our findings suggest a modality-specific fractionation encoding for auditory and visual rhythmic sequences. Besides, we propose the involvement of an auditory rhythm short term memory deficit contributing to the patient's rhythm impairment. A question of interest for future research is whether the isolated processing impairment for rhythm we have observed in this patient with left unilateral lesion is specific to professional musicians, or whether this impairment could be found in left damaged non-musician patients.

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