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Processing Prosodic and Musical Patterns: A Neuropsychological Investigation

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To explore the relationship between the processing of melodic and rhythmic patterns in speech and music, we tested the prosodic and musical discrimination abilities of two ''amusic'' subjects who suffered from music perception deficits secondary to bilateral brain damage. Prosodic discrimination was assessed with sentence pairs where members of a pair differed by intonation or rhythm, and musical discrimination was tested using musical-phrase pairs derived from the prosody of the sentence pairs. This novel technique was chosen to make task demands as comparable as possible across domains. One amusic subject showed good performance on both linguistic and musical discrimination tasks, while the other had difficulty with both tasks. In both subjects, level of performance was statistically similar across domains, suggesting shared neural resources for prosody and music. Further tests

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suggested that prosody and music may overlap in the processes used to maintain auditory patterns in working memory.

INTRODUCTION

Both speech and music use structured patterns of pitch, duration, and intensity. In speech, these elements are referred to as ‘‘prosody.’’ Similarities between the prosodic aspects of language and certain aspects of music have been noted for centuries (e.g., Steele, 1775; Bolinger, 1989) and have directly inspired several models of prosodic structure (Liberman & Prince, 1977; Hayes, 1984; Selkirk, 1984). Such notions make an implicit or explicit link between intonational and rhythmic aspects of language and the melodic and rhythmic dimensions of music. Yet these notions stand in contrast to claims in the neuropsychology literature that the processing of language and music is largely independent (Marin, 1989; Sergent, 1993; Peretz & Morais, 1989, 1993).

This contradiction in the literature probably reflects terminological ambiguity over what is meant by ‘‘melody’’ and ‘‘rhythm,’’ as well as the historical fact that the relation between the processing of these patterns in language and music has rarely been empirically addressed. Indeed, these two facts are probably not independent. Studying processing relations between prosody and music requires proper selection of appropriate aspects of melody and rhythm for cross-domain comparison. Musical melodic features such as a fixed-interval scale and the structural emphasis of a tonal center (Krumhansl, 1990) do not have any linguistic counterpart and in fact appear to be processed in a domain-specific way (Peretz, 1993). However, there are aspects of melody which are more appropriately compared to linguistic structures. ‘‘Melodic contour’’ is one such aspect. The term refers to the general shape of a melodic line (its patterns of ups and downs in pitch direction over time), without regard to exact pitch intervals. Contour’s role in melodic organization has been observed cross-culturally (Seeger, 1966; Bartók, 1967; Harwood, 1976; Roberts, 1996), and experimental studies have demonstrated its importance in music perception for both adults (Dowling, Kwak, & Andrews, 1995; Edworthy, 1985) and infants (Trehub, Thorpe, & Morrongiello, 1987). There is also a small body of research suggesting that contour can communicate emotion in music (e.g., Clynes and Nettheim, 1982; Gerardi and Gerken, 1995).

In speech, the closest analog to melodic contour is the trajectory of fundamental frequency (F_0) over time, which is commonly called ‘‘intonation.’’ Intonation is a basic part of the organization and perception of spoken language and contributes to marking the boundaries of structural units, distinguishing pragmatic categories of utterance (e.g., statement, question, command), and to signaling focus (Lehiste, 1973; Beckman & Pierrehumbert, 1986; Bolinger, 1989; Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991).

Intonation also communicates intention and affect, as in ''motherese,'' where highly salient intonational patterns are used to recruit the preverbal infant's attention and to communicate approval, disapproval, soothing, etc. (Fernald, 1985, 1993; Fernald and Kuhl, 1987). Sensitivity to intonation as an intentional and affective cue remains part of speech perception throughout life (Ladd, Silverman, Tolkmitt, Bergmann, & Scherer, 1985).

It appears that melodic contour and intonation can be appropriately compared, but what of rhythm? Choosing an analogous aspect of rhythm in language and music for perceptual study is hampered by the fact that no universally accepted definition of rhythm exists for either domain. However, most researchers agree to a conceptual division between *grouping*, referring to the clustering of adjacent elements with respect to temporal proximity into larger units, and *meter*, referring to a periodic temporal–accentual scheme. In music, meter and grouping are conceived as separate, though interacting, aspects of rhythm (see Lerdahl & Jackendoff, 1983, for a discussion of this issue).

At first glance, it would seem that meter is a promising candidate for the study of shared processing. Although simple notions of ''stress'' vs. ''syllable'' timing (Pike, 1945; Abercrombie, 1967) have not been supported by empirical data (Roach, 1982), there has been a continuing interest in meter by prosodists seeking to explain patterns of syllabic prominence in spoken language (e.g., Selkirk, 1984; Hayes, 1984). However, the primacy of metrical principles in explaining prominence patterns is disputed, and other mechanisms have been suggested to explain the observed patterns (e.g., Nespor & Vogel, 1989). Additionally, meter does not appear to be a universal feature of music, as there are examples from both within and outside the Western tradition of music without significant metrical organization. Exploring the link between language and music in this area is a challenging problem for future research.

There is reason to suspect that grouping may be a fruitful phenomenon for the investigation of processing relations between linguistic and musical rhythm. Research on read speech in English reveals that boundaries between groups of words are often marked by local slowing, called ''preboundary lengthening,'' with the degree of lengthening significantly related to the extent of the subjective decoupling between groups (Wightman, Shattuck, Hufnagel, Ostendorf, & Price, 1992). In music, sound elements tend to be grouped into larger units (e.g., ''phrases''), and the ends of these units also tend to be marked by slowing, with the degree of slowing reflecting the structural importance of the boundary (Todd, 1985; Gabriellson, 1987; Shaffer and Todd, 1987; Repp, 1992a, b). This parallel in constituent boundary-marking in speech and music has been noted by researchers involved in speech and music synthesis (Carlson, Friberg, Frydén, Granström, & Sundberg, 1989).

Given the structural similarities of melodic contour and speech intonation on the one hand and those of linguistic and musical temporal grouping on the other, it seems reasonable to expect that they share some processing and neural resources. Neuropsychology is well suited to address this question, as it can provide empirical evidence regarding the organization of processing components via patterns of dissociation and association after brain damage. While neuropsychological deficits in the processing of musical contour (Peretz, 1990) and linguistic intonation (Heilman, Bowers, Speedie, & Coslett, 1984) have been reported, they have been treated independently; to our knowledge, cross-domain comparisons have not yet been conducted. Neuropsychological evidence regarding grouping processes in language and music is even more scarce: while grouping processes in the temporal dimension in music can be disturbed by damage to each cerebral hemisphere (Peretz, 1990), we know of no neuropsychological studies of temporal grouping in language and a fortiori none across domains.

To address these issues, we have conducted a study examining the perception of linguistic prosody and musical structure in two amusic subjects. Selection of this particular neurological condition stems from a prior investigation in which an intriguing association between prosodic and musical impairments was observed (Peretz, Kolinsky, Tramo, Labreque, Hublet, Demeurisse, & Belleville, 1994). More specifically, CN, an amusic patient to be studied further here, was totally unable to discriminate musical patterns along the pitch dimension. In addition, she was found to experience deficits in processing some aspects of speech prosody. CN was impaired in judging intonation as well as in interpreting pause location in sentences, while her judgment of affective prosody was essentially intact. No firm conclusion regarding the commonalties between music and speech prosody deficits could be drawn in that former study because the tasks were not comparable. For music, ‘‘same–different’’ classification judgments were required. For speech, semantic categorization or metalinguistic judgments were employed. In such conditions, it is difficult to rule out task factors as potential contributing factors of the observed deficits. The present study was designed to eliminate these methodological limitations.

One of the main goals of this study was to design a test of prosodic and musical perception which was maximally comparable in terms of stimuli and task demands. We chose to rely principally on a same–different discrimination paradigm, using either sentence pairs which differed only in prosody or musical-phrase pairs derived from the prosodic features of the sentence pairs. For the prosodic differences we chose to use nonaffective (‘‘linguistic’’) rather than affective prosody, since the role of prosodic features in signaling linguistic differences such as focus, pragmatic category (e.g., statement vs. question), or syntactic relation (e.g., clause boundaries) is more clearly understood than its role in signaling affective categories (Price et al., 1991; Murray and Arnott, 1993).

We used two types of linguistic prosody to distinguish members of a sentence pair. Members of a pair could differ either by pitch accent placement (i.e., rising pitch to signal a question, falling pitch to signal a statement, or sentence-internal pitch to signal the focal word) or by timing (members of a pair differed in the placement of pauses). In order to create maximally comparable musical stimuli, we developed a technique for converting prosodic patterns to musical ones: specifically, for each sentence a tone sequence was synthesized which followed the pitch and temporal patterns of the sentence's syllables (in ''pitch accent'' sentences) or simply the temporal pattern of syllables (in ''temporal pause'' sentences). Thus the sentence pairs generated a corresponding set of musical-phrase pairs which were comparable in overall parameters such as length, rate, etc., as well as in more fine-grained patterns of frequency and/or timing. We felt that this approach was preferable to simply low-pass filtering the sentences because our technique removes all traces of phonological information. To our knowledge, this is the first study to use the technique outlined above.

Based on what we knew of the amusic subject CN, we predicted that she would have equivalent difficulty on the linguistic and musical stimuli. We also tested a new amusic subject, IR, who showed no signs of linguistic problems in standard aphasia testing. If she showed a dissociation of musical and prosodic processing, this would support the independence of music and prosody, while impaired performance across domains would provide evidence for shared processing resources between prosody and music.

METHOD

Subjects

The brain-damaged subjects, CN and IR, were both female native French-speakers, right-handed, and musically uneducated. They both had an analogous history of cortical damage in the left and right hemisphere due to aneurysms and surgical clipping of the middle cerebral artery on each side (IR also had left temporal lobectomy, involving excision of the anterior 5 cm of the left temporal lobe). As a result, at the time of testing both suffered from persistent amusia and neither experienced any significant aphasic problems. At the time of the present study, CN and IR were 40 and 38 years old and 7 and 9 years postsurgery, respectively. The first case, CN, has been described in detail elsewhere (Peretz et al., 1994; Peretz, 1996). The second case, IR, is a new case, of which a full description is forthcoming (Peretz et al., in press). Thus, only the results that are relevant for the present study will be summarized here.

CN. CN received 15 years of education and worked as a nurse. Several CT scans, taken several years apart, converged in revealing bilateral lesions of the rostral half of the superior temporal gyrus, though the transverse gyri of Heschl and caudal superior temporal gyrus appear to be intact (Fig. 1). There is extension of the lesions into the temporal poles and middle temporal gyri (bilaterally), the right insula, and to a limited extent, the right inferior frontal gyrus. Thus, the preservation of CN's speech and language functions is likely attributable to preservation of the left primary auditory area and putative language area of Wernicke. When we first tested CN in March 1988, 1 year after her second operation, she scored in the normal range on the BDAE and the Token test (DeRenzi and Faglioni, 1978). Her Full Scale IQ was 97 and her Wechsler memory MQ was 115, indicating normal intellectual and memory abilities for her age and education. Over the years, CN manifested persistent auditory deficits that involved the processing of music to a much greater degree than the processing of speech and

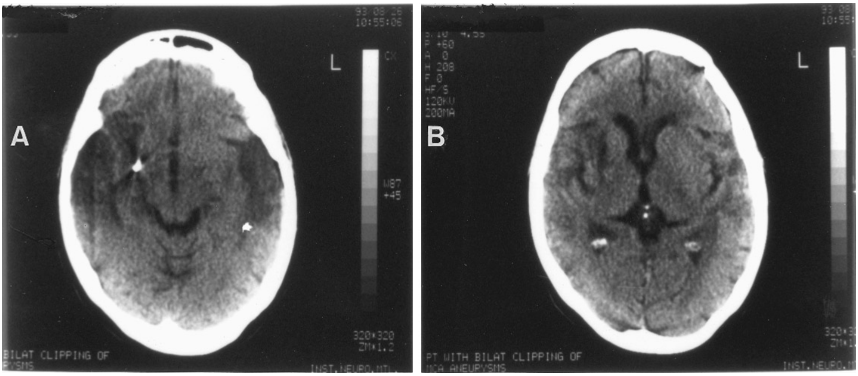


FIG. 1. Transverse CT scans at the level of the superior temporal lobe region of subject CN, taken in 1993. Note that the right side of the brain is shown on the left in each image. Scan B is 10 mm dorsal to scan A. Bilateral temporal lobe lesions are visible in Scan A as dark patches on the sides of the brain, at roughly one-third of the anteroposterior axis. The bright white dot in Scan A is due to a metal clip for an aneurysm. No damage is visible in scan B.

environmental sounds. To summarize the main findings, she exhibited: (1) impaired recognition of familiar tunes; (2) normal recognition of environmental sounds; (3) impaired perception of linguistic information but not affective information conveyed by speech prosody. Her expressive prosody has been assessed in both linguistic and affective contexts and was judged to be intact by experts in speech prosody (Shary Baum and Jack Ryalls, personal communication). The data presented in the current study were collected during the summer of 1993 when CN came to Montreal from Brussels to be tested.

IR. IR received 10 years of education and worked as a restaurant manager. CT scans taken in 1993 revealed an asymmetric pattern of damage in the two hemispheres (Fig. 2). In the left hemisphere, most of the superior temporal gyrus and all or nearly all of the transverse gyrus of Heschl are damaged; only a small portion of the posterior superior temporal gyrus is spared. The hypodensity extends anteriorly into posterior aspect of the frontal operculum, medially into most of the insula, inferiorly into the middle temporal gyrus, inferior temporal gyrus, and possibly the anterior parahippocampal gyrus, and posteriorly and superiorly into the anterior inferior parietal lobule and postcentral gyrus. In the right hemisphere, approximately the anterior one-third of the superior temporal gyrus is infarcted; all or most of the transverse gyrus of Heschl appears to be spared. There is extensive infarction of the right inferior and middle frontal gyri, precentral gyrus, and insula with extension into the lateral orbitofrontal gyri and putamen.

When we first tested IR, in September 1992, she scored in the normal range on the BDAE and the Token test. Although IR was initially diagnosed as a case of Wernicke's aphasia, we found no residual deficits in speech comprehension. Her Full Scale IQ was 94 and her Wechsler memory MQ was 99, indicating normal intellectual and memory abilities for her age and education. IR also manifested persistent auditory deficits, with music perception more affected than the perception of speech or environmental sounds. To summarize the main findings, she exhibited: (1) impaired recognition of familiar tunes; (2) impaired discrimination of unfamiliar tunes, including both pitch and temporal variations; (3) normal recognition of environmental sounds; (4) intact perception of affective information conveyed by speech prosody. Her expressive prosody appeared intact. However, IR was totally unable to sing, even an

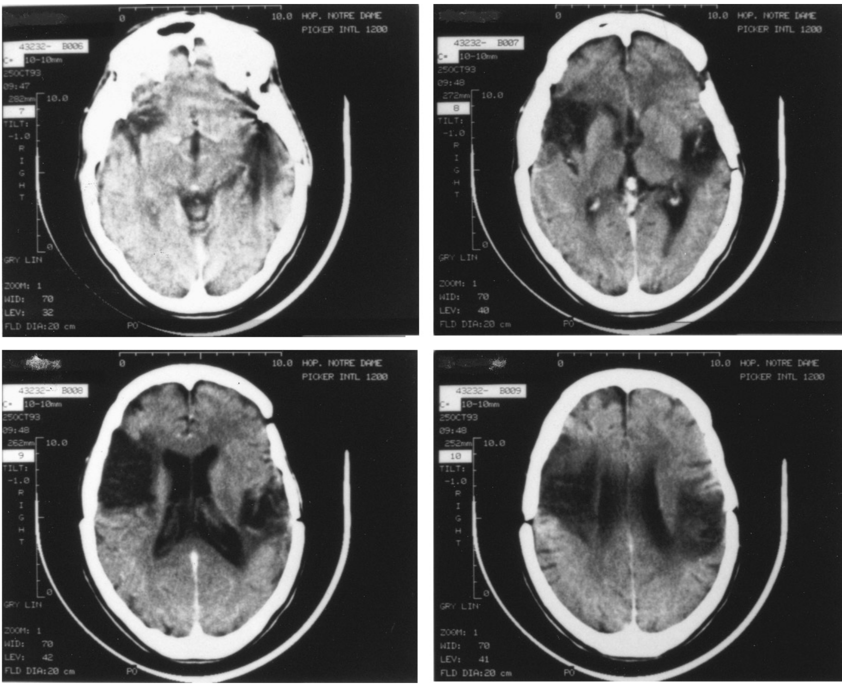


FIG. 2. Transverse CT scans of subject IR, taken in 1993. Note that the right side of the brain is shown on the left in each image. Scans proceed superiorly in 10-mm increments, in the order top left, top right, bottom left, and bottom right. The scans show bilateral temporal and right inferior frontal lobe damage (see text for details).

isolated single pitch. Thus, on the expressive side, IR appeared to exhibit a drastic dissociation between music and prosody. On the perceptual side with which we are more concerned here, IR suffered from a severe amusia involving basic melodic and rhythmic discrimination disabilities. Thus, IR's music agnosia pertains to the apperceptive type while CN's music agnosia pertains more to the associative type. Indeed, at the time of testing (e.g., in 1993), CN's deficits mostly concerned music memory abilities as demonstrated in another study (Peretz, 1996).

Control subjects. Eight female subjects with no history of neurological or psychiatric disease served as controls. Five of them were matched to CN in age (mean 40 years), musical background, and education (they were all nurses working in hospitals). Three were matched to IR, with an average of 41 years of age and 11 years of education. Since control subjects obtained very similar results in our tests, they will be considered as a single control group.

Materials

There were two sets of stimuli: 68 French sentences spoken by an adult female native speaker from France and 56 music-like patterns that were derived from the spoken sentences as follows. All sentences used in the experiment are listed in the Appendix.

Linguistic stimuli. The 68 spoken sentences were recorded by pair so that they were lexically identical but differed in prosody. For example, the sentence ''Il veut partir maintenant'' (he wants to leave now) was first pronounced as a statement and then as a question. There were 12 such statement–question (SQ) pairs. Twelve further pairs were generated so that they only differed by a shift in the word which bore the focus of the sentence. For example, ''Prends le *train* de Bruge, Anne'' (Take the *train* to Bruge, Anne) vs. ''Prends le train de *Bruge*, Anne'' (Take the train to *Bruge*, Anne): these will be referred to as focus-shift (FS) pairs. Ten additional pairs were generated so as to involve a change in grouping that corresponded to a difference in meaning. For example, ''Henri, le petit mange beaucoup'' (Henry, the child eats a lot) vs. ''Henri, le petit, mange beaucoup'' (Henri, the child, eats a lot): these will be called the timing-shift (TS) pairs. All sentences were spoken at a normal rate (avg. 4.7 syllables per s) and had a mean duration of 1.7 s (range: 0.96–2.22 s). The sentence pairs were digitized at 40,000 Hz and normalized to the same amplitude (1 V RMS). Acoustic manipulations described below were performed using SIGNAL (Engineering Design, Belmont, USA) on a modified 486 personal computer.

All the statement–question pairs were acoustically adjusted to match patterns of syllable timing and amplitude between members of a pair, yielding sentence pairs in which fundamental frequency was the only salient cue for discrimination. This adjustment involved three steps for each pair: (1) The duration of the final word (which always bore the rising or falling pitch movement) was equalized, phoneme by phoneme, by duplicating or deleting portions of the acoustic waveform in regions of stable harmonic structure (e.g., noise, steady-state portion of vowel, or the silence corresponding to a stop closure). (2) The amplitude profiles of the final words were equalized. In all cases, the lower-amplitude final word (usually the statement) was scaled up in amplitude to match the higher. This was done in order to maximize the salience of the final word, which then sounded perceptually about equally loud. (3) One sentence member in each pair was chosen as a ''stem'' sentence: all of its words up until the final word provided the stem onto which the adjusted final words were grafted. In half the pairs the statement member provided the stem; in the other half, the stem came from the question. Since the sentences in a pair did not differ markedly before the final word (e.g., in declination pattern), and there were no marked differences in timing or intensity of syllables, this splicing procedure produced natural-sounding sentence pairs matched for timing and intensity patterns, but differing in fundamental frequency.

This procedure was applied to half the focus-shift pairs, so that fundamental frequency was the major salient cue for discrimination.[1] The other half of the focus-shift sentence pairs were left unmanipulated: here the cues to focus-shift included patterns of intensity and duration, in addition to fundamental frequency. These unmanipulated sentences served as controls, to determine if discrimination problems occurred in contrasting sentences of natural speech, where focal prominence is signaled by multiple prosodic cues.

[1] In the focus-shift pairs, the durational adjustments and splicing procedures were used on the words which signaled focus (these words were always marked by a salient pitch accent). Thus, a word in focus in one sentence had the same duration when it appeared in the other sentence. However, equalizing the intensity of focal and nonfocal versions of the same word proved more difficult. Unlike the statement–question final words, the focal vs. nonfocal versions of a word had large differences in pitch *and* amplitude as originally spoken, and perceptual interactions between these differences led to the failure of the envelope or energy matching strategy to produce words equal in loudness. Matching loudness of syllables in a psychoacoustically rigorous way requires an explicit model that combines frequency and amplitude-modulated spectra and temporal integration to produce a loudness curve. We did not find a convincing model of this type, so loudness was matched perceptually by listening to the two versions of a word (in sentence context) and adjusting their amplitudes until they sounded equally loud.

Members of each timing-shift pair were distinguished by the timing of their constituent syllables: however, these differences were correlated with other prosodic cues. For example, the presence of an embedded modifying adjective phrase (as in ''Henry, le petit, mange beaucoup'' versus ''Henry, le petit mange beaucoup'') was associated with an upward pitch glide on the final syllable of this phrase (''pe*tit*'') and on the noun preceding this phrase (''Hen*ri*''), while in the absence of this phrase the same syllables had downward sloping glides. Equalizing the pitch contours of these sentences makes them sound unnatural, and was thus not pursued. Unfortunately, this meant that the sentences had differences other than their temporal pattern and thus cannot provide a totally ''clean'' test of timing perception in speech. Nevertheless, we decided to include them as a preliminary attempt to study temporal grouping in language, with the hope that eventually they would be replaced by more controlled stimuli. Since pitch was not equalized between members of a pair, no effort was made to match the amplitudes of corresponding syllables, because the waveform suggested that whatever amplitude differences existed were small compared to pitch and timing differences.

Music-like stimuli. The melodic pairs were generated from the fundamental-frequency and timing pattern of syllables in the 12 statement–question pairs and the 6 adjusted focus-shift pairs. Since these sentence pairs were matched for timing and loudness, each resulting melodic pair yielded two temporally matched sequences differing only in pitch contour. No melodic analogs were made from the acoustically uncontrolled focus-shift pairs, since the analogs, like their parent sentences, would have differed in parameters other than pitch contour (e.g., timing).

The process of making a melodic phrase from a sentence involved the following 3 steps (illustrated in Fig. 3):

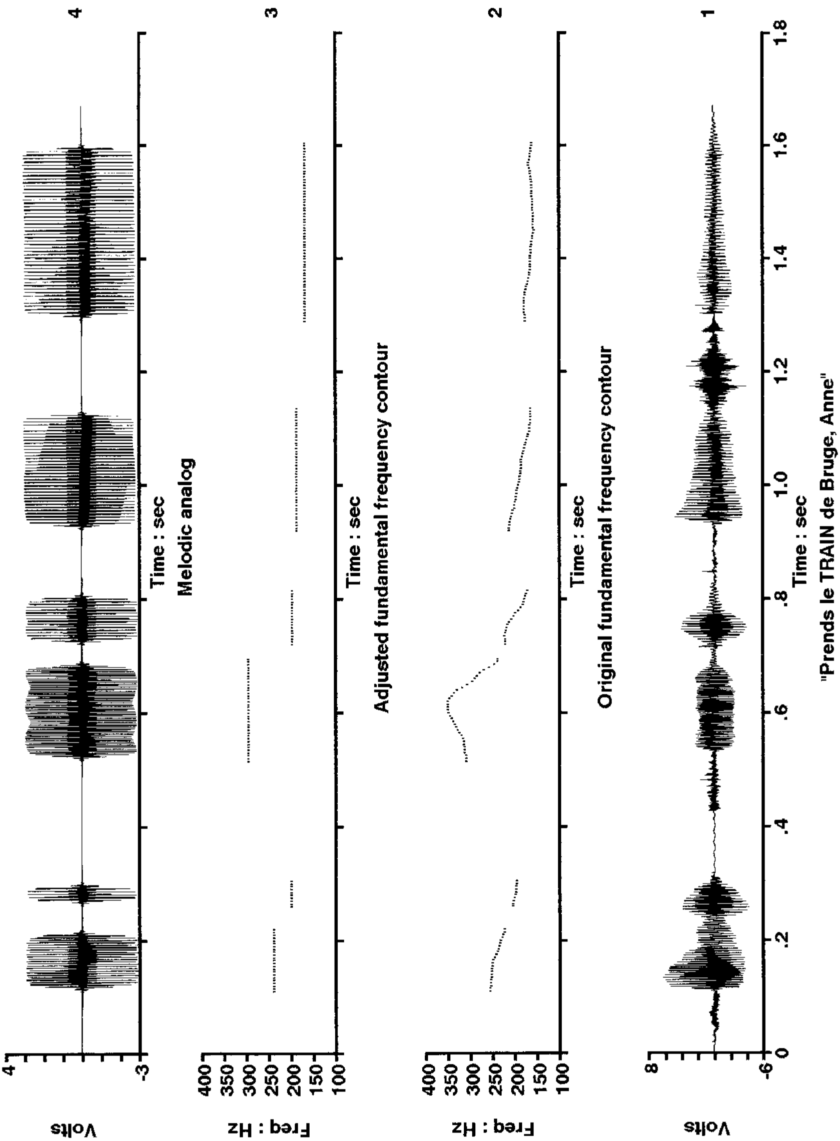
(1) The fundamental-frequency (F_0) contour of the sentence was obtained from the lowest harmonic of a narrow-band spectrogram. Due to frequency–time resolution trade-off in Fourier analysis, increasing frequency resolution is achieved at the cost of lower time resolution: the values selected here were 19.5 Hz and 51.2 ms resolution, respectively. The F_0 contours thus generated were checked against those produced by another algorithm (''harmonic sieve,'' Klatt speech analysis system, MIT) and were found to match quite well.

(2) The resulting contour was time-aligned to the original sentence waveform. The contour was marked at syllable boundaries as detected in the waveform and determined auditorily. If a clear marker could not be found in the waveform, a spectrogram was made and the boundaries of segments were determined via spectral cues. If the contour was not naturally interrupted at the boundary (i.e., for syllables beginning with stops, where no voicing is present), the contour was set to zero Hz for 10–15 ms before and after each marker. The resulting contour represented the timing of the voiced portions of each syllable in the sentence.

(3) Although the fundamental frequency of each spoken syllable was always a glide of some sort, the pitch of each tone was fixed at its parent syllables' median F_0 ([max + min]/2), plus two integer harmonics. This created a discrete intervallic structure between tones, contributing significantly to making the sequence sound nonlinguistic while still preserving the ''melody'' of the sentence from which it was derived. All tones were given the same amplitude (3 V) and rise/decay time (15 ms), and the mean amplitude of the entire melodic sequence was matched to that of its parent sentence (1 V RMS). The melodies had a sample rate of 5000 Hz.

It should be noted that no attempt was made to make the pitches or intervals of the melodies correspond to the Western musical scale. While this precluded the experiment from addressing the perception of tonality, it allowed the experiment to address the perception of musical contour versus speech intonation in a precise fashion.

The rhythmic sequences were generated from the 10 timing-shift pairs: the durational pattern of syllables in each pair was used to create a pair of tone sequences of fixed frequency, differing only in temporal organization. It should be noted that these rhythmic sequences did not conform to any metrical scheme. Also, by eliminating any variation in frequency, they did not sound as much like their linguistic counterparts as the melodic sequences did. However, they


4
3
2
1
Volts
Freq : Hz
Freq : Hz
Volts
Time : sec
Melodic analog
Time : sec
Adjusted fundamental frequency contour
Time : sec
Original fundamental frequency contour
Time : sec
"Prends le TRAIN de Bruge, Anne"

did reflect the temporal patterning of the original sentences, which grouped their syllables differently according to the meaning of the sentence. The exact procedure for making rhythmic pairs was identical to that described above for melodic pairs, except that the tones were all set to a single frequency (200 Hz: the estimated mean F_0 of the speaker).

Procedure

The linguistic and musical stimuli were arranged into a series of discrimination tests and tests of prosodic understanding, as follows.

Prosodic discrimination. The ability of subjects to discriminate between sentences differing in prosody was tested with two sets of materials. The first set consisted of the statement–question and focus-shift pairs (the pitch intonation set), and the second set consisted of the timing-shift pairs. In each set, a given sentence pair appeared in both ''same'' and ''different'' configuration, with a few randomly selected pairs repeated. This yielded 60 pairs for the pitch intonation set and 24 pairs for the timing-shift set. Subjects listened to one pair at a time and decided whether the two stimuli were ''same'' or ''different.'' The temporal interval within and between pairs was 2 and 5 s, respectively.

Musical discrimination. Musical discrimination was tested with two sets of musical stimuli derived from the linguistic stimuli. The first set consisted of melodic pairs derived from the statement–question and focus-shift pairs, and the second set consisted of the rhythmic pairs derived from the timing-shift pairs. As with the language stimuli, in each set a given pair appeared in both ''same'' and ''different'' configuration, and a few randomly selected pairs were repeated: this yielded 48 pairs for the melodic set and 24 pairs for the rhythmic set. The task and temporal intervals between stimuli were identical to those of the Prosodic Discrimination tests.

Statement-question categorization. This test checked the ability of a subject to map prosodic information onto a pragmatic category when no other cues (e.g., lexical, contextual) were available. The statements and questions that were used in the Prosodic Discrimination tests were presented one at a time in random order. The subject was simply required to classify each sentence as ''statement'' or ''question.'' Thirty stimuli were presented (12 statements, 12 questions, and 6 randomly chosen replicates) with 4 s in between for responding.

Accent detection. This test determined if a subject could correctly identify the word bearing a pitch accent in a sentence. The focus-shift sentences were presented one at a time in random order. The subject indicated from a choice of three words for each sentence which word was most prominent (responses were made by circling the selected word on a response sheet). For example, if the sentence was ''Allez devant le *banque,* j'ai dit'' (Meet me in front of the *bank,* I said), the subject selected the accented word from the three choices: devant, banque, dit. Thirty stimuli were presented (24 focus-shift sentences and 6 replicates) with 4 s in between for responding.

Syntactic interpretation. This test assessed the ability to use prosodic information to disambiguate syntactic structure. The subject was presented with a question to which only one member of the following timing-shift pair was the correct answer. Upon hearing the pair, the subject

FIG. 3. The process of making a melodic phrase from a sentence is illustrated in four panels for the focus-shift sentence ''Prends le TRAIN de Bruge, Anne.'' Panel 1 shows the sentence waveform. Panel 2 contains the fundamental frequency of the sentence: each syllable is represented by one segment of the F_0 contour. In panel 3, each syllable's F_0 contour has been fixed at a level value corresponding to the [(max + min)/2] point of the underlying F_0 contour. The contour in panel 3 is used to synthesize the musical analog, whose waveform is shown in panel 4.

TABLE 1
Performance on Prosodic and Musical Discrimination Tasks

	Statement-question		Focus shift		Focus shift (control)	Timing shift	
	Linguistic (No. correct out of 30)	Melodic (No. correct out of 30)	Linguistic (No. correct out of 16)	Melodic (No. correct out of 16)	Linguistic (No. correct out of 14)	Linguistic (No. correct out of 22)	Rhythmic (No. correct out of 24)
CN	29	31	15	14	12	22	18
	$\chi^2 = 0.245$		$\chi^2 = 0.446$			$\chi^2 = 2.288$	
	$p = 1.00$		$p = 1.00$			$p = .25$	
IR	27	24	8	10	4	13	14
	$\chi^2 = 2.300$		$\chi^2 = 0.526$			$\chi^2 = 0.113$	
	$p = .19$		$p = .72$			$p = 1.00$	
Controls ($n = 8$)	29	30	15	15	12	23	22
	(27–30)	(28–32)	(13–16)	(14–16)	(9–14)	(22–24)	(19–24)
	$\chi^2 = 0.366$		$\chi^2 = 0.242$			$\chi^2 = 0.434$	
	$p = 1.00$		$p = 1.00$			$p = 1.00$	

Note. Cross-domain statistical comparisons are provided below each pair of scores. Values in parentheses below control scores represent range values.

made a choice by indicating ''first'' or ''second.'' For example, after the question ''Dans quelle phrase Henry est-il un enfant/In which sentence is Henry a child?'', the subject heard the phrases ''Henry, le petit mange beaucoup/Henry, the little one eats a lot,'' and ''Henry, le petit, manage beaucoup/Henry, the little one, eats a lot.'' 10 seconds were given between pairs for responding. Eight of the timing-shift pairs were used in this test, along with eight questions designed specifically for this task. The questions and stimuli were presented twice; on second presentation, the order was reversed. This yielded a total of 16 trials.

Pause detection. We included one additional test for use with subjects who had difficulty discriminating timing-shift sentences or their rhythmic analogs. The test checked whether the discrimination problem might be due to a low-level problem with the *detection* of pauses in acoustic sequences. The test consisted of 30 sequences of five to eight 125-ms tones (200 Hz + 2 integer harmonics) presented at a rate of 4 tones/s. Half of the sequences had a pause of 250 ms in the sequence (i.e., equivalent to omitting a tone from an otherwise isochronous sequence). The subject listened to one sequence at a time and decided if it contained a pause or not. Four seconds were given after each sequence for responding.

Testing procedure. Subjects were seated comfortably in a quiet room and the tests were presented over speakers at a comfortable level. Prosodic Discrimination and Musical Discrimination tests were completed first in a counterbalanced order across CN and IR, followed by the other tasks. Subjects were not informed that the musical stimuli were derived from the linguistic ones. Two practice trials were given for each test except Statement–Question Categorization, due to its simplicity. Subjects were tested in two sessions, each lasting about 1 h.

RESULTS

Prosodic and Musical Discrimination

To address the issue of the relationship between linguistic and musical processing, the proportion of correct responses on analogous linguistic and musical tasks was assessed for both CN and IR (Table 1). All statistics reported below were done on raw scores using the Fisher exact probability test for nonparametric comparison of proportions. Control data were represented by the average score of the eight control subjects. For each comparison, the Fisher statistic (χ^2) and p value are given: none reached significance. The Fisher test revealed that for CN and IR, performance did not differ significantly across domains (i.e., analogous linguistic and musical tasks), a pattern that was also true of controls. CN's performance was not significantly different from controls on any task. IR, in contrast, performed worse than controls on the Focus-Shift task in language ($\chi^2 = 7.51$, $p < .02$) and music (marginally significant: $\chi^2 = 4.38$, $p < .08$) and on the rhythmic discrimination tasks in language and music ($\chi^2 = 11.49$, $p < .01$, and $\chi^2 = 7.07$, $p < .03$, respectively).

Unlike CN, IR was found to perform at chance on most tasks. Since the number of same and different pairs differed, due to the fact that replicates were chosen randomly and not counterbalanced along the same/different dimension, chance performance was assessed by comparing the actual distribution of ''same'' and ''different'' pairs with the subjects distribution of ''same'' and ''different'' responses, using the Fisher Exact Test. The absence of significant dependence between these proportions was considered as chance performance. Following this logic, IR was found to perform above chance only on statement–question pairs and their musical analogs ($\chi^2 =$ 22.1 and 8.69, respectively, $p < .01$).

It should be noted that for both amusic subjects and controls, performance on the manipulated and unmanipulated focus-shift pairs did not differ significantly ($\chi^2 = 0.61$, 1.39, and 0.61 for CN, IR, and controls, respectively, all $p > 0.20$). Finally, we administered the pause-detection task to IR, as she had difficulty with discriminating timing-shift sentence pairs and their rhythmic analogs. IR performed very well on this task, with 29 correct responses out of 30.

Statement-Question Classification, Accent Detection, and Syntactic Questions (Tests of Prosodic Understanding)

Performance by amusic subjects and controls on these tasks is shown in Table 2. Neither of the amusic subjects had any difficulty with simple classification of statements vs. questions. CN had no difficulty with the accent-detection task. IR did somewhat worse (77% correct), but was still well above chance (chance taken to be 33% correct: $\chi^2 = 11.394$, $p < .01$). This stands in contrast to her performance on discriminating focus-shift sentences, where she was at chance (only 40% correct). On the syntax questions, CN and IR performed very similarly, despite the fact that CN was greatly superior to IR in discriminating the timing-shift sentence pairs on which this task was based (cf. Table 1). Despite their low scores, the difference from control scores was not significant, as this task was difficult for controls as well ($\chi^2 =$ 1.35 and 2.23, for CN and IR, respectively, both $p > .20$).

TABLE 2
Performance on Additional Prosody Tasks

	Statement-question classification (No. correct out of 30)	Accent detection (No. correct out of 30)	Syntactic questions (No. correct out of 16)
CN	30 (100%)	30 (100%)	10 (63%)
IR	30 (100%)	23 (77%)	9 (56%)
Controls (n = 8)	30 (100%) (28–30)	28 (94%) (27–30)	13 (81%) (11–15)

Note. Values in parentheses below control scores represent range values.

DISCUSSION

The aim of the present study was to investigate the relation between the processing of prosodic and musical patterns. With comparable tasks and stimuli in the linguistic and musical domain, we have observed parallel effects: the preservation of both prosodic and musical discrimination skills in one amusic subject, and impairments of both skills in another. As more fully explained below, CN's and IR's performance support the view that the perception of speech intonation and melodic contour share certain cognitive and neural resources, as do the perception of rhythmic grouping in the linguistic and nonlinguistic domain.

It is obvious that prosodic and musical processing share resources at certain neural levels: there are not separate cochlea for language and music. On the other hand, it is equally obvious that at some point melodic and rhythmic patterns and linguistic prosody follow separate processing pathways, i.e., building tonal relations in music or semantic relations in language. This study attempts to elucidate whether there is an intermediate level at which the representation of prosodic and musical patterns overlaps in a nontrivial way.

CN showed sparing of both basic prosodic and musical discrimination abilities. Her deficits appear primarily to involve long-term memory for melodies (Peretz, 1996) and the perception of tonality (Steinke, Cuddy, & Peretz, 1994). Our study highlights the specificity of her musical deficits and suggests that her difficulties can shed light on those aspects of music processing which are independent of language. However, her performance cannot shed light on any particular stage(s) at which prosodic and musical processing overlap. The amusic subject with impaired performance on our prosodic and musical tasks (IR) is of greater interest in this regard, and the details of her performance hold a clue to the stage at which prosodic and musical processing are still intertwined.

It is worth noting that IR is a case of ''amusia without aphasia,'' and thus in the past might have been taken as a priori evidence of the dissociability of language and music. However, IR's performance reminds us that reported dissociations between language and music can reflect only the particular tasks administered to a subject: her difficulty in discriminating sentences which differed in prosodic focus is a linguistic deficit which did not emerge in standard aphasia testing. IR showed this difficulty whether the acoustic cue to focus was specifically pitch or a naturally covarying set of cues including pitch, duration, and intensity. Her difficulty cannot be attributed to a failure to encode pitch: she was able to discriminate statement–question pairs and their melodic analogs, where she reported concentrating on the final pitch in the sequence. The focus-shift trials, however, had the critical pitch located *within* the sequence. IR's good performance on the accent-detection task showed that she can *perceive* sequence-internal pitch. However, the focus-shift discrimination task and its melodic analog require pitch *patterns* to be maintained in memory. This ability appears severely compromised in IR.

In other words, IR seems to have a deficit in processes involved in the short-term retention of musical contour and intonation. Similarly, IR's difficulty in discriminating sentences that differed in timing (and their rhythmic analogs) is likely to be due to a memory problem: her difficulty cannot be attributed to a basic problem with the detection of pauses, as she performed very well on our Pause Detection task. Thus it appears that holding pitch and temporal patterns in short-term memory is a stage at which linguistic and musical information recruit similar procedures or resources.

In this regard, it is worth contrasting the lesion profiles of IR and CN, as the difference in their patterns of neural damage could help suggest the involvement (or lack thereof) of specific neural regions in short-term memory for pitch and temporal patterns. In light of previous cytoarchitectonic (Galaburda & Sanides, 1980; Rademacher, Caviness, Steinmetz, & Galaburda, 1993) and electrophysiologic (Celesia, 1976; Liegeois-Chauvel, Musolino, & Chauvel, 1991) data, CN sustained bilateral lesions of rostral auditory association cortex with sparing of primary auditory cortex and caudal association areas. IR also sustained extensive bilateral injury to anterior auditory association cortex, but differed notably from CN in left-sided injury to primary auditory cortex and excision of anterior temporal lobe cortex, and in extensive injury to lateral frontal cortex on the right. By homology with connectivity patterns in anthropoids (Pandya & Yeterian, 1985), IR's lesions suggest complete or near-complete bilateral disruption of input from auditory cortex to prefrontal cortex—in the left hemisphere, principally because of injury to auditory cortex and underlying white matter, and in the right hemisphere, principally because of injury to lateral frontal cortex and underlying white matter. Projections from auditory cortex to medial temporal cortex may also be disrupted to some degree in the left hemisphere.

Thus, the lesion and behavioral data obtained from CN and IR suggest that left primary auditory cortex and right prefrontal cortex may play an important role in the retention and comparison of pitch and temporal patterns in both musical and linguistic domains. These results are consistent with data from recent metabolic neuroimaging studies (with normals), implicating right frontal circuits in the retention and comparison of pitches in both melodic phrases (Zatorre et al., 1994) and syllables (Zatorre et al., 1992). However, it should be kept in mind that IR had bilateral lesions, suggesting the interaction of brain regions in different hemispheres in prosodic and musical processing.

Of course, as with any case of functional association, the possibility exists that the prosodic and musical processes in question are in fact neurally and functionally distinct, and were disrupted together by overlapping lesions: this issue can be resolved only by further testing. We are aware of one previous report where localized brain damage (right fronto-temporal damage atrophy) led to deficits in musical and prosodic perception, but the *relation* between melodic and intonational processing was not empirically assessed or quantified (Confavreux, Croisile, Garassus, Aimard, & Trillet, 1992). It is also possible that the association between prosodic and musical processing reported here is due to a general auditory short-term memory deficit which disrupts the retention of auditory patterns of any kind. Another study (Belleville and Peretz, forthcoming) reveals that IR showed short-term memory deficits in a wide variety of musical and verbal tasks (including digit spans); this working memory deficit is limited to the auditory modality since IR is not impaired in the short-term retention of visuo-spatial information (such as block locations and faces). Only further testing can reveal whether the resources used in short-term storage of prosodic and musical patterns are also relevant to other kinds of patterns of sound (e.g., environmental sounds).

One way to address the specificity of the prosody–music link is to test subjects known to have prosodic deficits (preferably without short-term memory problems) for their musical perception abilities. Cases of prosodic perception deficits following brain damage come to light much more frequently than cases of amusia. ''Aprosodia'' can be due to damage to the right or left hemisphere (Ross, 1981; Cancelliere and Kertesz, 1990; Blonder, Bowers, & Heilman, 1991) or to subcortical regions (Brådvik, Dravins, Holtås, Rosén, Ryding, & Ingvar, 1991), but its relation to perception of music has yet to be investigated. Most of the studies to date focus on aprosodia as a deficit of affective perception, but recent work suggests that there may be a more basic underlying deficit in the perception of pitch and temporal cues (Van Lancker & Sidtis, 1992). This is supported by the finding that certain aprosodic subjects have problems with *linguistic* prosody (Weintraub et al., 1981; Baum, Daniloff, Daniloff, & Lewis, 1982; Heilman et al., 1984; Emmorey, 1987), suggesting that they can be fruitfully tested with the types of stimuli and tasks discussed here. Given our findings, we predict that an association between prosodic and musical processing would be maintained.

A last point concerns the validity of our music-like stimuli as effective triggers of genuinely musical processes. Since our music patterns derived from linguistic sentences, they did not obey the rules of the Western musical system. Assuming that musical processes develop through the abstraction of regularities from samples of this system, it may be the case that our music-like patterns did not fit these regularities and were thus not processed by music-specific processes. One might even argue that the contours were so ''speech-like'' that they were processed in the ''speech mode'' (Liberman & Mattingly, 1989). However, we doubt that pitch sequences which lack any phonological information and use stable pitches with discrete pitch intervals could engage speech-specific processes: indeed, if they did, the ''specificity'' of those processes to speech would be seriously called into question. However, the question remains whether our music-like stimuli engaged processes normally used in the perception of music. If musical contour perception is triggered by culturally familiar tonal patterns, then our music-like stimuli may not have truly tapped musical perception. This seems unlikely, however, since it would force the odd conclusion that one could not perceive pitch contours in unfamiliar musical systems. Our study suggests that the level of domain-specificity in music processing is ''above'' the level of musical contour, but more work is needed before the boundaries of music-specific processing can be firmly delineated.

The experiment outlined above shows that performing comparable analyses of linguistic and musical processing in amusic subjects leads to a gain in the specificity of deficit characterization and can sharpen our understanding of the role of implicated neural regions in both musical and linguistic processing. The study also suggests that before a deficit is diagnosed as domain specific (i.e., ''pure amusia,'' or for that matter, ''pure aprosodia'') comparable tasks should be administered in other domains. We believe that the tasks and stimuli reported here could be of use in probing the relation between prosodic and musical processing in a variety of subject populations, especially those with well-defined temporal and/or frontal lobe dysfunction and those with ''aprosodic'' perception deficits. One obvious extension of the test is to vary the intrapair stimulus interval in order to explore the rate at which short-term memory of pitch or temporal patterns decays in subjects with different lesion profiles. Finally, we hope that the idea of using sentence pairs controlled for timing and loudness but differing in pitch may also prove helpful to those interested in probing the processing of linguistic prosody in neurally compromised populations.

APPENDIX

Statement–Question Pairs

1. Il parle Français./?
2. François est au restaurant./?
3. Elle boit trois grandes tasses de café chaque matin./?

4. Il veut partir maintenant./?
5. Elle joue de la flute./?
6. Il aime conduire des voitures rapides./?
7. Il veut acheter une maison près de la plage./?
8. Elle a déjà lu ce livre./?
9. Il était à Paris depuis trois mois./?
10. Le super-marché est fermé le dimanche./?
11. Il travaille dix heures par jour./?
12. Le téléphone ne marche pas./?

1. He speaks French./?
2. Francis is at the restaurant./?
3. She drinks three large cups of coffee every morning./?
4. He wants to leave now./?
5. She plays the flute./?
6. He likes to drive fast cars./?
7. He wants to buy a house next to the beach./?
8. She forgot her book./?
9. He has been in Paris for three months./?
10. The supermarket is closed on Sunday./?
11. He works ten hours a day./?
12. The telephone doesn't work./?

Focus-Shift Pairs

1. Allez *devant* la banque, j'ai dit.
   Allez devant la *banque,* j'ai dit.
2. J'aime les *cravates* bleues.
   J'aime les cravates *bleues.*
3. Donnez-moi l'examen de *mathématique* aujourd'hui.
   Donnez-moi l'examen de mathématique *aujourd'hui.*
4. Tu *chantes* bien, Paul.
   Tu chantes *bien,* Paul.
5. Les *fleurs* oranges sentent tres bons.
   Les fleurs *oranges* sentent tres bons.
6. Prends le *train* de Bruge, Anne.
   Prends le train de *Bruge,* Anne.
7. Le *livre* de Paul est chez moi.
   Le livre de *Paul* est chez moi.
8. Le *parapluie* orange coute moins cher.
   Le parapluie *orange* coute moins cher.
9. Il *aime* lire des romans romantiques.
   Il aime lire des *romans* romantiques.
10. C'est la *soeur* de Jacques, n'est-ce pas?
    C'est la soeur de *Jacques,* n'est-ce pas?
11. Prends le *train* de Bruge, Anne.
    Prends le train de *Bruge,* Anne.
12. *Chantez* maintenant, sil vous plait.
    Chantez *maintenant,* sil vous plait.

1. Go in *front* of the *bank,* I said.
2. I like *blue ties.*
3. Give me the *math* exam *today.*

4. You *sing well*, Paul.
5. The *orange flowers* smell very sweet.
6. Take the *train* to *Bruge*, Anne.
7. *Paul's book* is at my house.
8. The *orange umbrella* is less expensive.
9. He likes to *read* romance *novels.*
10. It's *Jack's sister*, isn't it?
11. Take the *train* to *Bruge*, Anne.
12. *Sing now*, please.

Timing-Shift Pairs

1. Henri, le petit mange beaucoup.
   Henri, le petit, mange beaucoup.
2. Merci c'est le mot juste.
   Merci, c'est le mot juste.
3. Jacques, le sportif court vite.
   Jacques, le sportif, court vite.
4. Paul, mon ami est beau.
   Paul, mon ami, est beau.
5. Anne, sa femme est grosse.
   Anne, sa femme, est grosse.
6. Il s'appelle Jean, Pierre.
   Il s'appelle Jean-Pierre.
7. Madame Lafleur est le nom de mon chat.
   Madame, Lafleur est le nom de mon chat.
8. François, le chef est prêt à commencer.
   François, le chef, est prêt à commencer.
9. Monsieur le professeur veut parler avec vous.
   Monsieur, le professeur veut parler avec vous.
10. Dis-moi la phrase, ''vous êtes beau'', Henri.
    Dis-moi la phrase, ''vous êtes beau Henri.''

1. Henry, the little one(,) eats a lot.
2. Thanks(,) (it) is the right word.
3. Jack, the athlete(,) runs quickly.
4. Paul, my friend(,) is handsome.
5. Anne, his wife(,) is fat.
6. He is named Jean(,) Pierre.
7. Madame(,) Lafleur is the name of my cat.
8. François, the chef(,) is ready to begin.
9. Mister(,) the professor wants to speak with you.
10. Say the sentence, ''you are handsome''(,) Henry.

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