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Boundaries of separability between melody and rhythm in music discrimination: A neuropsychological perspective

Isabelle Peretz ^a & Régine Kolinsky ^b

^a Université de Montréal , Montreal, Canada

^b Université Libre de Bruxelles , Brussels,
Belgium

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**Boundaries of Separability
between Melody and Rhythm
in Music Discrimination:
A Neuropsychological Perspective**

Isabelle Peretz

Université de Montréal, Montreal, Canada

Régine Kolinsky

Université Libre de Bruxelles, Brussels, Belgium

The detailed study of a patient who suffered from a severe amelodia without arhythmia as a consequence of bilateral temporal lobe damage revealed that the processing of melodic information is at least partially separable from the processing of rhythmic information. This dissociation was replicated across different sets of material, was supported by the presence of a reversed association, and was maintained in conditions that promote integration in the normal brain. These results argue against the view that melody and rhythm are treated as a unified dimension throughout processing. At the same time, they support the view that integration takes place after early separation of the two dimensions.

In the domain of music processing, there are two essential dimensions: the melodic dimensions—arising from pitch variations, and the rhythmic dimension—due to temporal variations. These two dimensions have long been treated independently, both in theory (for example, Deutsch & Feroe, 1981, and Krumhansl & Kessler, 1982, for pitch organization models; Povel, 1984, and Longuet-Higgins & Lee, 1982, for temporal

Requests for reprints should be sent to Isabelle Peretz, Département de Psychologie, Université de Montréal, CP 6128 succ.A, Montreal (Que), H3C 3J7, Canada.

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organization models) and in practice (see any textbook on music cognition, such as that of Sloboda, 1985, and of Dowling & Harwood, 1986). Recently, this tradition has been seriously put into question by Jones, Boltz, and their collaborators (Boltz, 1989a, 1989b, 1989c; Boltz & Jones, 1986; Jones, 1987; Jones, Boltz, & Kidd, 1982). They argue, quite persuasively, that melody and rhythm are not psychologically independent but, rather, are integrated in music perception and memory—i.e. listeners treat melody and rhythm as a unified dimension in musical sequences. Consequently, most past studies that have dealt with only one dimension without regard to the other may have overlooked essential principles of organization in music. The present study aims to clarify this issue of integrality by means of neuropsychological dissociations.

In the present research, we rely on simple definitions of these melodic and rhythmic structures, which arise from sequential variations along the relevant dimension, because our purpose is mainly to explore their dissociability after brain damage. This rather crude distinction is facilitated by the fact that pitch structure can be defined independently of temporal structure in music, and vice versa. Thus, the dissociability issue is not one of definition but, rather, one of processing. More specifically, the question at issue is whether listeners' percept of musical sequences results from an interaction of melody and rhythm, or else from an independent influence of each of these. In the following, we will refer to these two positions as the "single-component" model (or the "dynamic" model, following the terminology of Jones and her collaborators) versus the "two-component" model (or the "independence" model), respectively.

The few studies that have considered both melody and rhythm in combination have yielded mixed results with respect to these two models. In support of the single-component model are findings that rhythmic patterns that conflict with melodic structure yield a much poorer performance than when the two coincide. Such integrality effects have been observed in written recall (Boltz, 1991; Boltz & Jones, 1986; Deutsch, 1980) and in delayed recognition (Jones & Ralston, 1991; Jones, Summerell, & Marshburn, 1987; but see Smith & Cuddy, 1989, for negative results). The fact that these tasks have an important memory load does not appear to be the responsible factor, as a similar outcome has been obtained in more perceptually oriented tasks, such as "same-different" classifications (Jones et al., 1982) and phrase-completion judgements (Boltz, 1989a, 1989b, 1989c). Moreover, interactive effects of rhythm and melody manipulations have been observed in selective attention tasks; when subjects are explicitly instructed to ignore the melodic dimension, they still exhibit response patterns that are affected by this dimension (Jones, 1987; Pitt & Monahan, 1987) and conversely for the rhythmic dimension (Boltz, 1989a; Kidd, Boltz, & Jones, 1984).

However, other studies have obtained results that are more compatible with the two-component model, in that melodic and rhythmic structures exerted independent influences. These findings were obtained with tasks involving either very long-term memory (Halpern, 1984) or more perceptual discriminations, such as similarity ratings for pairs of musical segments (Monahan & Carterette, 1985; Monahan, Kendall, & Carterette, 1987) and phrase completion (Palmer & Krumhansl, 1987a, 1987b). Thus, task factors cannot easily account for the discrepancy between this set of studies, on the one hand, and that supporting the single-component model, on the other.

One possibility that would allow reconciliation of both sets of results within a single framework is to conceive melody and rhythm as separate perceptual components that are later integrated to produce a unified experience of the musical segment. This conceptualization conforms to most current views of the information processing sequence being broken into two main stages, each of which admits further decomposition. The initial main stage consists of input analysis systems that operate in parallel on very specific aspects of the environment, usually in pre-attentive and mandatory fashion. These perceptual computations are thought to be followed by focal or attentive analyses, which are also flexible and subject to decisional evaluation. This view has been made particularly explicit by authors such as Fodor (1983) for all input domains, and Treisman (1986) for vision in particular. When applied to the present case of early separation between rhythm and melody, this view requires that the observation of independent influences or interactive effects is dependent upon the processing stages consulted by the listener or tapped by the task requirements. The problem with such an account is that, presently, we do not know at what stage in the processing of musical information the percept is integrated. Hence, perceptual independence might prove to be very difficult to verify. Experiments on perception usually require subjects to make decisional evaluations, which can fundamentally alter the percept. *A fortiori*, if integration is taking place at the decision-making stage or just before, evidence of perceptual independence may remain elusive, at least in the normal brain.

Neuropsychology can provide evidence of such a "disconnection-like" behaviour, resulting from brain damage. To the extent that any two components are processed by two independent systems and that these systems are implemented in separable neural structures, damage restricted to one of them may deprive the decision-making process of its specific computations; this would leave the undamaged system to determine the final decision. Such a logic underlies most observations of neuropsychological dissociations. If a patient can no longer process the rhythmic structure of musical sequences but is able to process the melodic structure, then the

dissociation pattern argues for the processing autonomy of rhythm and melody. The inference is even stronger if another patient is found to display the inverse dissociation—that is, a loss of melodic abilities and the sparing of rhythmic ones. The two patients or dissociation patterns then constitute an instance of a double dissociation, which, in turn, provides a strong support for the two-component model. Alternatively, if a single system underlies the joint processing of melody and rhythm, any damage to this system should affect the processing of both components.

The available evidence is actually more compatible with the two-component model than with that of the single-component. The first suggestions of dissociations between the processing of melody and rhythm arose from other spheres of musical behaviour than the auditory one. In singing, rhythmic variations can be preserved while melodic variations are impaired (Mann, 1898, and Jossman, 1926, reported in Dorgeuille, 1966); conversely, melodic variations can be spared while rhythmic variations are defective (Brust, 1980; Mavlov, 1980). In reading music, the same picture emerges with a selective impairment of rhythm (Brust, 1980; Dorgeuille, 1966), or of melody (Assal, 1973; Dorgeuille, 1966). Thus, these earlier reports all point towards a dissociation between melodic and rhythmic phenomena in music, albeit in an indirect way, in that reports are usually not supported by quantitative data, and they touch upon other sensory spheres than audition. Recently, however, we have extended this double dissociation between rhythm and melody to the perceptual domain (Peretz, 1990). Using a “same–different” classification task, we discovered two patients who performed at chance level when the discrimination cue was melodic, but who performed normally when the cue was rhythmic. Conversely, two other patients were found to be at chance on the rhythmic dimension, but to perform normally on the melodic one. Thus, these findings support the notion that rhythm and melody are processed by at least partially distinct systems. However, the evidence relied on a preliminary exploration of a hitherto little-studied subject. As such it suffers from some methodological weaknesses. Therefore, the major goal of the present study was to improve upon these, by distinguishing rhythm and melody processing in a more thorough and robust manner.

To this aim, we studied a new patient, C.N., who happened to exhibit the dissociation in a clear-cut fashion as a consequence of brain damage. C.N. was found to be unable to perceive melodic variations. This severe impairment occurred in isolation from disturbances in the processing of rhythmic information. Her particular pattern of breakdown will first be described. Then, her results will be presented, along with those from normal matched controls obtained in two different experimental settings.

The first experiment aimed to establish the dissociation between rhythm and melody across different sets of material and, in doing so, to apply the logic of reversed association (Dunn & Kirsner, 1988). This method has

been recently proposed as a powerful means of distinguishing between two tasks and, by inference, the underlying processing components. The logic is as follows. If two tasks are mediated by a single processing system, the data should be related in a monotonic fashion across conditions—that is, performance on one task should always be either an increasing or a decreasing function of performance on the other task. Accordingly, any pattern of data that involves violation of such a monotonic relation between the two tasks provides evidence for rejection of a single-component model. To obtain such a departure from monotonicity, one basically needs to observe a positive (monotonically increasing) relation between two tasks under one change of condition, and a negative (monotonically decreasing) relation between such tasks under another change of condition. This particular pattern is referred to as a “reversed association” by Dunn and Kirsner (1988) and has been illustrated with neuropsychological data (taken from Graf & Schacter, 1985) by the authors. In that illustration, amnesic patients are compared to normal controls on word retrieval as a function of their associative link in a cued recall task and a stem completion task. In general, a positive relation between cued recall and stem completion was observed. Subjects tended to retrieve more related words than unrelated ones in both tasks. However, a negative relation was also observed across two particular conditions; for the related words in the amnesic group and for the unrelated words in the controls, an increase in performance on the word completion task was accompanied by a decrease in cued recall. Thus, stem completion performance could not be expressed as a monotonic function of cued recall performance. This is taken as sufficient evidence to reject the single-process model, following Dunn and Kirsner’s logic.

As described in greater detail further on, the inclusion of two different sets of material allows us to exploit this method in the present study. If rhythm and melody are indeed dissociable at the processing level, they may be expected to be positively related for one set of material, or in one neuropsychological condition, while being negatively related under a change in one or the other condition. Obtention of this pattern would allow formal rejection of the single-component model in a more straightforward fashion than through the observation of a dissociation. Compelling dissociations are more difficult to observe experimentally than reversed associations, as the former require performance on one task to be absolutely unaffected by changes of material.

The second experiment was directed towards eliciting “disconnected” responses in C.N.—that is, demonstrating that C.N.’s performance was no longer influenced by melodic variations. To this end, it was necessary to compare C.N.’s behaviour to that of normal subjects (with healthy brains) in situations that promote integration of melody and rhythm. As mentioned at the outset, such situations are not readily derived from the literature on

normals as opposite results have been observed for identical task parameters (i.e. Boltz, 1989a, b; Palmer & Krumhansl, 1987a, b). Therefore, in conformity with the same task and material used in Experiment 1, we created a Stroop-like situation. Subjects were required to compare sequences as "same" or "different", according to the rhythmic dimension—the only dimension on which C.N. could reliably perform. However, the melody also varied in half the trials, thus creating a potential conflict with the rhythmic information. The idea was that if melodic information could not be completely ignored (i.e. if integration did take place), accuracy should be higher when melody and rhythm yield congruent responses than when they do not. This integrative behaviour was expected to be elicited in normals, but not in C.N.

GENERAL DESCRIPTION OF C.N.'S AMELODIA WITHOUT ARHYTHMIA

C.N. was referred to us in March of 1988 for a pure amusic disorder. A follow-up study of her performance has been in progress since then. The results to be reported hereafter were collected by us between March 1988 and March 1989, a period during which C.N.'s performance was stable. During the summer of 1989, slight improvements in performance were noted; therefore only the results obtained before this period were included in the present study. At that time, C.N. was 35 years old and had undergone successive brain surgeries (both in 1986 and 1987) to have aneurysms clipped in the middle cerebral arteries bilaterally. After the second operation, C.N. presented with persistent amusia, but no other neuropsychological deficit. The CT examination revealed sequellar lesions in both temporal lobes.

C.N. is a fully right-handed female nurse, with 15 years of formal education. At the time of testing, she scored within the normal range for all standardized tests. Her I.Q. on the WAIS intelligence scale was 97 (verbal: 99, performance: 95) and her M.Q. on the Wechsler memory scale was 115. Speech comprehension and expression were completely spared, as attested by a perfect score on the French adaptation of the Boston Diagnostic Aphasic Examination test (Goodglass & Kaplan, 1972). In contrast, recognition and humming of well-known tunes (without lyrics) were both severely impaired. Although C.N.'s musical profile is that of a non-musician, she was a music lover, and she used to sing every day to her child. A full case description can be found in Peretz, Kolinsky, et al. (submitted).

As a departure point for the present study, C.N.'s ability to process the melodic and rhythmic dimensions of musical sequences was tested with a battery of subtests, henceforth referred to as screening tests. Full description of these tests is to be found in Peretz (1990). These screening tests

aim to assess the discrimination of various musical aspects that are known to contribute to music processing, while keeping the material as natural and constant across conditions as possible. The material consists of a pool of 24 novel but tonal musical sequences that are arranged in different conditions. These were played on a piano by a professional and recorded on audio tapes. The control data were provided by five normal subjects whose ages and socio-economic backgrounds closely matched that of C.N. (age mean: 33.6 years, range: 29–40; education mean: 14.6 years, range: 13–15; all were right-handed, and most were nurses working in hospitals like C.N.). The results are presented in Table 1.

In the "isolated pitch" condition, two piano tones were presented successively, and the task was to judge whether or not their pitches were identical. 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. C.N.'s performance was quite high (with 21 of the 24 items correct). This was later replicated with another test, which was created for a different purpose and was employing synthesized complex tones (each made up of four sine waves in harmonic relation) differing in pitch distance from 1 to 5 semitones (from Peretz, Paquette, & Lecours, submitted). C.N. made only two errors out of the

TABLE 1
Percentages of Correct Responses Obtained on the Screening Tests¹ by C.N. at the Time of Testing² and by Five Normal Controls

	C.N.	Controls		
		Mean	Lowest Score	Highest Score
<i>Isolated pitch discrimination</i>				
piano tones†	87.5	94.2	79.2	100.0
synthesized complex tones*	96.6	97.2	95.0	100.0
<i>Melodic dimension</i>				
contour-violated†	33.3	85.0	75.0	95.8
contour-preserved†	33.3	70.8	50.0	83.3
tonal closure*	59.4	91.6	84.4	100.0
<i>Rhythmic dimension</i>				
metric*	80.8	81.7	65.4	96.2
grouping*	87.0	96.7	86.5	100.0

¹Peretz (1990).

²March, 1988.

†Chance level being at 33.3%.

*Chance level being at 50%.

60 trials presented. Thus, her performance fell well within the range of 24 normal subjects of similar age (taken from Peretz, Paquette, & Lecours, submitted) (see Table 1).

However, an impairment in pitch judgement appears when these must be made in a melodic context. As 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 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, C.N. was found to be completely unable to employ melodic cues to discriminate the musical sequences. In other words, whether or not the melodic cue involved a change of pitch direction did not influence her performance; she invariably responded “same”.

In the last melodic condition, referred to as “tonal closure” in Table 1, C.N. also encountered difficulties. In this test, eight melodies used in the previous conditions, with all temporal variations removed, were presented, ending in either a tonic or a non-tonic tone. The non-tonic ending was diatonic (in the key of the melody) and was selected so that it was as close as possible in pitch height to the tonic (i.e. with a maximal distance of two semitones). All the endings followed a descending pitch direction. Each stimulus was presented twice in random order. Subjects were required to indicate whether or not the melody was complete. On this test, C.N.’s score did not differ from random performance using a binomial test (chance being 50%). Thus, at the time of testing C.N. did not give the slightest indication that she could perceive and/or interpret pitch variations in melodies.

This complete loss of discrimination abilities for pitch patterns, referred to as “amelodia”, stands in sharp contrast to her preserved abilities to discriminate melodies along the rhythmic dimension. C.N. performed in the low, but within normal, range when discriminating rhythmic patterns, as shown in Table 1. Both temporal grouping (tested by a “same–different” classification task bearing on the tapped version of the melodies presented in the melodic conditions) and metric judgements (assessed by a “waltz–march” classification task) were reasonably well preserved. Thus, C.N. displayed no evidence of “arhythmia”.

It is worth mentioning that comparison of C.N.’s data with that of controls yields the observation of a classical dissociation between the processing of melody and rhythm, following Shallice’s (1988) terminology (see Figure 1). Effectively, for identical task requirements (that is, “same–different” comparison tasks), C.N. exhibits a clear deficit in melodic organization: her score is below the lowest score obtained by control subjects in the two melodic conditions (contour-violated and contour-preserved condi-

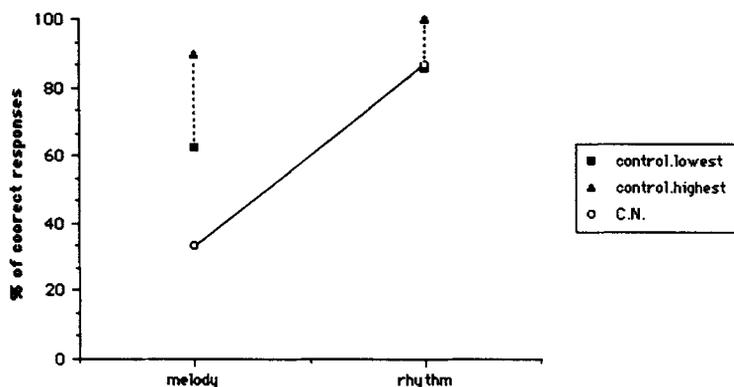


FIG. 1. Percentages of correct responses obtained by C.N. on the melodic and rhythmic screening tests. Dotted lines indicate the normal range.

tions). Yet, she displayed normal performance in rhythm discrimination: her scores are situated within the range of controls. This suggests that C.N. performed the rhythm test roughly at the same level as before the onset of her illness, in so far as it is possible to infer from the use of closely matched controls. In other words, her rhythmic performance is not just relatively preserved but spared in comparison to her severe melodic impairment. This type of dissociation is qualified as around the most robust (i.e. conforming to the "classical" pattern), because it cannot easily be accounted for by differences in measurement scales. Nevertheless, this possibility cannot be completely ruled out either. To do so would require the observation of a double dissociation or of a reversed association. The latter can be assessed by means of single case methodology and is assessed in Experiment 1.

EXPERIMENT 1

The present experiment aimed to establish the dissociation between the processing of melody and rhythm observed in C.N. with different materials, which are also better matched than were our screening tests. Adjustment of the material was desirable for a number of different reasons. (1) The previous screening tests contained twice as many "different" trials as "same" ones, for pragmatic reasons (see Peretz, 1990, for details). This unbalanced proportion was eliminated here, in order to avoid response biases and ascertain that chance level was indeed 50% correct. (2) The screening tests incorporated melodic manipulations in sequences varying in rhythmic context as a between-trial factor, whereas the rhythmic manipulations were inserted in sequences devoid of melodic variations. For purposes of comparison, it is preferable to study each dimension in

similar contexts. Here, this was achieved by “neutralizing” variations in the irrelevant dimension. In the melodic conditions, the pitch patterns were made equitemporal (that is, with tones of equal duration). In the rhythmic conditions, the temporal patterns remained equitonal (i.e. temporal patterns formed of tones with a constant frequency). (3) The level of difficulty differed between our two screening tests. Normal performance in the rhythmic grouping condition was higher than in the melodic conditions (see Table 1 and Figure 1). This raises the possibility that the rhythmic tests are simply not sensitive enough to detect a deficit. Although our previous observation of clear-cut deficits (i.e. at chance level) on these tests (Peretz, 1990) makes this criticism rather unlikely, it is still preferable to replicate C.N.’s dissociation with materials that are better matched for difficulty.

It turned out that manipulation of task difficulty, especially on the rhythmic dimension, is a difficult goal to achieve. There is no clear indication in the literature that allows us to infer what are the proper parameters affecting task difficulty. Therefore, we chose rather arbitrarily, following a previous study of ours (Peretz & Morais, 1983), to manipulate the extent of changes. In the screening tests, the changes inserted in the musical sequences to be compared within a trial were of a local nature. That is, a single pitch—and thus two interval sizes—was modified on the melodic dimension, and approximately two durations were interchanged on the rhythmic dimension. We will refer to these tests as the “local set”. In the present experiment we also added a global set. In the latter, modifications were global in that they affected the relevant dimension for every tone. Pilot results indicated that these global modifications did succeed in approximating a match in performance level between the melodic condition and the rhythmic condition. Even when performance levels between the discrimination of melody and the discrimination of rhythm are successfully matched, it does not necessarily imply that the respective resource demands are equivalent. Thus, two conditions may be of such different levels of resource demands that they produce different patterns of performance after a brain lesion, while still being mediated by the same processing system. Task difficulty (or resource demands) is a very sensitive issue that needs to be considered seriously when arguments for a dissociation at the underlying processing level are the goal (Shallice, 1988). As a stronger test of dissociability, comparison of performance on the local set and on the global set allows one to overcome this problem by taking advantage of the reversed association logic proposed by Dunn and Kirsner (1988). This method requires consideration of at least three constraints. As opposed to the screening situation, this could be fulfilled here due to the addition of a supplementary experimental set.

Method

Materials and Apparatus. There were two sets of stimuli, described hereafter by the proportion of modified tones. In each set, the changes affected either the melodic dimension (i.e. the melodic condition) or the rhythmic dimension (i.e. the rhythmic condition). In all four conditions, the stimuli were arranged in trials obeying the following structure: each trial consisted of a warning signal that preceded a target melody, which, in turn, was followed after a 2-sec silent interval by the comparison melody. Half of these trials were created by pairing a target melody with itself, and the other half consisted of the same target melody paired with a different comparison. These were recorded in a random order, with an intertrial interval of 5 sec. For each condition, the experimental trials were preceded by two practice trials. The trials were all generated on an IBM AT-compatible microcomputer controlling a Yamaha TX-81Z synthesiser. The chosen tempo was fixed at 120 crochets per minute, and the voice was a synthesized pan flute. The analog output was recorded on a cassette taperecorder, which was also used to play back the tapes to subjects.

The local set corresponded to the sequences used in the screening subtests. The rhythmic condition was equivalent, in that it involved the same stimuli; the only difference was that here it was presented by a computer instead of being played by a musician. There were 24 different target melodies, of which half were modified to create alternate comparisons. This was realized by interchanging the duration values of two to three tones, while maintaining the total number of tones (see B in Figure 2). The serial position of these changes varied across stimuli. The melodic condition was also derived from the screening tests, and they involved more substantial changes than the rhythmic condition. First, all sequences were made equitemporal, so that all tones were of the same duration. They were also matched in length to the rhythmic sequences, containing between 6 and 11 tones (mean = 8.2). Otherwise, the modified pitches in any comparison sequence were identical to those manipulated in the screening tests. These changes were relatively local, modifying a single pitch in a "different" comparison (see A in Figure 2). Half of these differing pitches were modified so that the pitch direction of the surrounding intervals are changed (as in A, Figure 2); these alternate melodies corresponded to the "contour-violated" screening condition. The remaining differing pitches were modified to the same magnitude (in terms of semitone distance) but preserved the original contour of the target melody; these comparison melodies corresponded to the former "contour-preserved" condition. These different types of pitch manipulations were intermixed in the melodic condition. There were 48 trials blocked in this condition as well as in the rhythmic condition.

	TARGET	COMPARISON	Condition
LOCAL SET	A	A	Melodic
	B	B	Rhythmic
GLOBAL SET	C	C	Melodic
	D	D	Rhythmic

* : local changes

FIG. 2. Examples of "different" trials for each dimension of each material set used in Experiment 1.

The *global set* was constructed similarly to the local set. This was realized by constructing sequences from a limited pool of six different motifs of three tones each, along each dimension. Any stimulus was a particular arrangement of three motifs on the relevant dimension, with the restriction that none of the motifs could be repeated. In the melodic condition, there was a further constraint, in conformity with the melodic cues manipulated in the local set. Half of the differing comparison sequences were composed of motifs that violated the contour of the target (e.g. C in Figure 2 where the first motif violates the contour), half were made of motifs that preserved the contour of the target melody. There were 24 trials in each condition.

Procedure. Subjects were run individually in each of the four conditions (two conditions per set) on different days, in a different order. They listened to the prerecorded tapes free field via two loudspeakers located in front of them. Their task was to judge whether the sequences, on each trial, were identical or not. They all responded verbally "same" or "different". No feedback on their accuracy of response was provided. Control subjects were three new subjects and one subject who had served as control in the screening tests. They were selected along the same criteria and participated as controls in this experiment as well as in Experiment 2.

Results

As expected, C.N.'s performance was poorer with melodic variations than with rhythmic variations. Only 52.1% and 62.5% of her responses provided in the melodic conditions of the local and the global set, respectively, were correct. She scored no better than chance (by a binomial test at $p < 0.05$)

in either condition. In contrast, she performed significantly above chance on each rhythmic test. On the latter, she obtained 85.4% and 77.8% correct, for the local and the global set, respectively. Control subjects performed well above chance in all conditions. These results are summarized in Figure 3.

In order to assess statistically whether C.N.'s dissociation between melody and rhythm was reliable, different analyses were performed on these scores. (1) As only four normal subjects participated, and in order to facilitate comparison with the pattern of results for C.N., the data were analysed separately with items as the random factor rather than subjects. (2) The method of reversed association (Dunn & Kirsner, 1988) was applied to the results.

Normal Subjects. The score associated with each item was the sum of the two responses given by all subjects to the two trials using the same item for the target (i.e. a "same" and a "different" trial), thus allowing for a maximal score of eight correct responses per item. These scores were then submitted to a two-factor analysis of variance (ANOVA) taking each set (global vs. local) and each dimension (melodic vs. rhythmic) as factors. This analysis yielded an interaction between the set and the dimension manipulated, $F(1, 68) = 13.53, p < 0.001$. The rhythmic manipulations were found to be far easier to discriminate than the melodic changes in the local set, $F(1, 46) = 18.91, p < 0.001$, but such was not the case for the global set, where the trend was even in the opposite direction [$F(1, 22) = 2.04$].

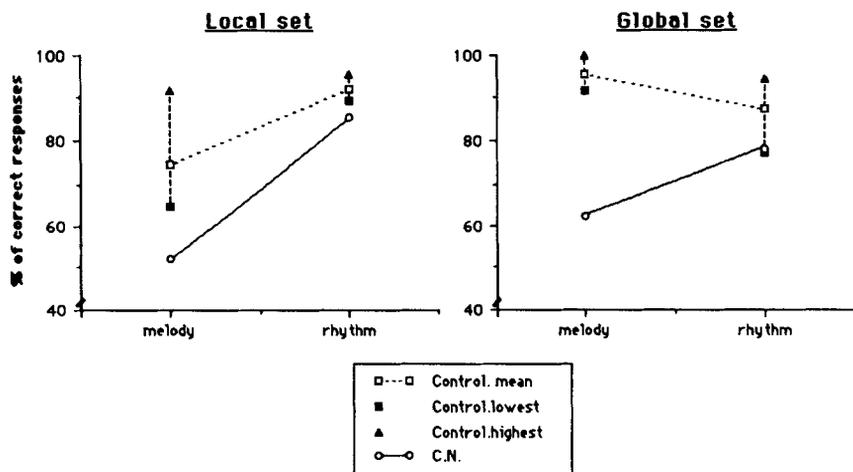


FIG. 3. Percentages of correct responses obtained by C.N. and controls on the melodic and rhythmic conditions as a function of the material set. Dotted lines indicate the normal range.

C.N. The same ANOVA as that performed on controls' scores was performed on *C.N.*'s data. This yielded a main effect of dimension, $F(1, 68) = 25.04$, $p < 0.001$, and no significant Dimension \times Set interaction [$F(1, 68) = 2.00$]. Therefore, unlike control subjects, the superiority of rhythmic discrimination over melodic discrimination did not differ according to the set of material under consideration (i.e. as a function of the extent of changes inserted in the melodies to be compared).

Reversed Association. We examined whether or not the data pattern obtained here between the discrimination of rhythm and melody reveals a reversed association—that is, a non-monotonic relation. To do so, it is necessary to plot performance on melody as a function of performance on rhythm for the different conditions common to both dimensions. Such a plot is shown for the present results in Figure 4. When viewed in this manner, the data show clear violation of monotonicity. Thus, a reversed association is obtained.

Discussion

The present results provide strong evidence that discrimination of melody and rhythm can be differentially affected by a lesion to the brain. Here, this proposition is based on both the finding of a classical dissociation, replicated across different sessions and materials, and a reversed association, allowing us to disregard difficulty as a potentially confounding factor.

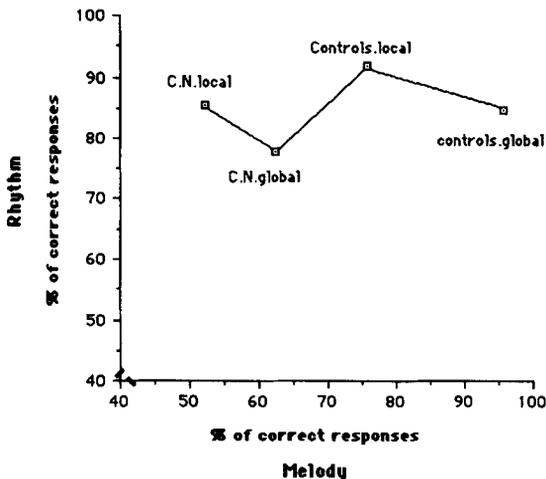


FIG. 4. Percentages of correct responses for the discrimination of melodic cues plotted as a function of the percentages of correct responses for the discrimination of rhythmic cues by controls and by *C.N.* for each dimension of each material set.

In the first place, the outcome can hardly be attributed to the decision-making processes, as rhythmic and melodic discrimination were performed under identical task demands. In both conditions, the subjects were required to perform a “same–different” classification task. Secondly, the dissociation appears to be robust. In effect, converging evidence was obtained from multiple tests. C.N. performed at chance on both tests involving melodic discrimination, as was the case on the screening tests. In contrast to this poor performance, she performed well on the two corresponding tests involving rhythmic discrimination, as was also the case on the screening tests. This situation fulfils one of the fundamental requirements stipulated by Tulving (1987) for the distinction of processing systems by means of dissociations. Indeed, dissociations between tests are suggestive of the existence of distinct systems, yet other interpretations are also usually possible. What is critically required, in this context, is the use of multiple tasks. The logic of the argument is rather straightforward. If a variable, such as a focal brain lesion, has an effect on performance in tasks A, B, and C but has no effect on tasks X, Y, and Z, “then it can be concluded that tasks A, B, and C have something in common that X, Y, and Z do not” (p. 70). The converging evidence of this nature is provided here by C.N.’s recurrent failure on melodic tests and systematic preservation on rhythmic tests.

The fact that we have replicated the screening results here with C.N. is noteworthy. The present findings not only increase the confidence of our assertion in the original study (Peretz, 1990), but also add some other interesting indications. In effect, the local set presented here contained some minor improvements that were made in the screening tests. These adjustments did not notably change the results, thus suggesting that certain musical caricatures (i.e. synthesized and unidimensional) yield results similar to those of more natural material. C.N.’s performance did not fluctuate and remained poor, irrespective of the temporal context in which she was required to detect pitch changes, whereas she maintained a fairly good level of rhythmic discrimination. Nonetheless, a negative consequence of replicating our former results is that “caricaturization” did not help to adjust performance level differences between the two conditions of the local set. That is, the rhythmic condition remained generally easier to perform than the melodic condition. This is probably a consequence of the discrepancy in terms of the number of modified events, which was larger in the rhythmic condition. In the global set, however, there was a reverse trend. The rhythmic condition appeared slightly more difficult than the melodic condition, although not to a significant degree. The counter-intuitive aspect of these data is that global manipulations of the temporal structure appeared slightly more difficult for subjects to apprehend than are local manipulations—both for normals and for C.N. However, this

observation may simply reflect the fact that, in our Western culture, rhythmic sequences are highly stereotyped and very regular, whereas pitch structures are richly varied and elaborate. Thus, global modifications of rhythm, effected by changing every durational value, may have produced highly complex and somewhat artificial stimuli to the Occidental ear. This may, in turn, account for the relatively lower performance level observed for the global rhythmic set compared to the local set, the format of which indeed included rather monotonous patterns.

This difficulty in matching rhythm and melody in terms of complexity may be related to the general fact that the type of manipulation operating on one dimension is not necessarily equivalent to the one operating in the other. A fortiori, if rhythm and melody are processed by distinct mechanisms, these two can be attuned to different structural characteristics. Therefore, one is required to observe very large differences in performance, i.e. as perfect versus chance performance, to affirm the presence of a dissociation. Yet, as explained previously, even such a marked effect cannot completely rule out the possibility that the two dimensions are processed by a single system. The dissociation must take a specific form if it is to provide evidence for the operation of functionally distinct systems. Just such a result was found here in the form of a non-monotonic relation, i.e. a reversed association between rhythm and melody.

EXPERIMENT 2

In Experiment 1, we reached the conclusion that the dissociation found in C.N. between the processing of melody and rhythm is not due to artefacts of difficulty levels and thus could hardly be explained by damage to a single processing component. Such results strongly suggest that melody and rhythm are treated separately at some level in the processing of musical information. Yet it is very likely that rhythm and melody are integrated in the cognitive system, as discussed in the introduction. The locus of these integration effects is still unknown; it may take place very early, during processing of the incoming information, or rather late, near the decision stage. Nevertheless, wherever integration takes place, we posited in the introduction that a severe disturbance in the processing of one of the two dimensions would not permit integration, but would rather produce a disconnection-like functioning of the spared component. The present experiment was directed towards demonstrating this phenomenon.

With this goal in mind, we needed to explore how rhythm and melody are jointly processed by C.N., in a situation where normal listeners reveal integration effects. Such situations are not readily derived from the literature on normals, as previously described. Therefore, retaining the task parameters used in Experiment 1, we applied to the present case a standard

method underlying much research done in vision. This method is basically a variation on Stroop's (1935) classic paradigm.

In Stroop-like situations, integration of two dimensions is inferred when variations along an irrelevant dimension have deleterious effects on the responses to the relevant dimension. This interpretation goes back to the original findings of Stroop (1935), who showed that naming ink colours is dramatically impaired if the coloured stimulus happens to be a word that names a colour that is different from the actual ink colour (e.g. the word "green" printed in red ink). The term "Stroop interference" has since been generically applied to any drop in performance attributable to the integration of the irrelevant dimension being incongruent with, and calling for the opposite response, to the relevant dimension. Indeed, it is unlikely that reading words and perceiving colours are the product of a single system—hence the attribution of the Stroop effect to the integration of distinct and incongruent responses.

Stroop logic can also be applied to the processing of melody and rhythm in a "same-different" classification task. It entails that interference may occur when responses "same" (S) or "different" (D) are in conflict between the dimension to which subjects are required to attend and the dimension that must be ignored. In principle, such a task can be performed following either rhythm or melody as the relevant dimension for comparison. In the present case, however, the relevant dimension had to be the rhythm, in order to allow C.N. to perform reliably. To ensure valid comparisons, control subjects were also required to ignore melodic information and to classify sequences according to rhythm alone. In this case, Stroop interference is expected to arise from the failure to ignore melodic variations. Thus, in general, responses should be more accurate when they match (i.e. SS and DD, where the first and the second member refer to the type of trial on the rhythmic and melodic dimension, respectively), than when they do not match (SD and DS). This prediction will be referred to as the incongruity interference effect. Moreover, further specific predictions can be formulated as a function of response type. On S trials, accuracy should be higher when there is no difference on the melodic dimension (SS) than when there is one (SD), because conflict occurs in the latter case. For the same reason, the reverse pattern is expected on D trials; accuracy should be higher when there are differences on both dimensions (DD) than where no melodic variation is introduced (DS).

The presence of these interactive effects, resulting from a conflict between the decision and the content of irrelevant melodic changes (i.e. Stroop effects), will be taken as evidence that melody and rhythm are integrated. Unless melodic information is completely separable from rhythmic information, which is doubtful given the existing evidence, normal subjects are expected to display these interference effects. In

contrast, C.N. should be immune to the content or the presence of melodic variations, and thus should exhibit none of these effects.

Method

The stimuli for the melodic and rhythmic conditions of the local set used in Experiment 1 were combined here to produce bi-dimensional melodies. The choice of this set, instead of the global set, was motivated by the fact that C.N. repeatedly exhibited a high level of accuracy on the rhythmic dimension with this material. There were 48 experimental trials divided equally into four categories. In the “same” category of trials (S), sequences always possessed the same temporal structure; each sequence served twice as target, once in a trial where the comparison sequence was identical, i.e. without melodic change (SS), and once where the comparison contained a melodic change (SD). Similarly, in the “different” type of trials (D) the sequences always had a different temporal structure; half of the comparison sequences contained a pitch change (DD) and half did not (DS). The material was generated and presented in the same manner as in Experiment 1.

Subjects were required to ignore melodic variations and to concentrate only upon rhythm. They had to decide whether the rhythm was “same” or “different”. C.N. was presented twice with the same material but in two sessions separated by two weeks, in order to increase the number of observations per response category. As C.N.’s pattern of performance did not differ between the two sessions, they will not be distinguished in the following analyses.

Results

First, a substantial incongruity interference effect was obtained in control subjects, indicating that the situation was appropriate for eliciting Stroop-like effects. Control subjects achieved 66.7% correct on the incongruent trials (SD and DS), whereas they were 89.6% correct on the congruent trials (SS and DD), $\chi^2 = 14.04$, $p < 0.001$. Every normal subject displayed this effect. In contrast, C.N. did not show evidence of a conflict: she was 83.3% and 81.1% correct on the incongruent and congruent trials, respectively.

The direction of the conflict between rhythmic information and melodic information should, however, differ as a function of response type. This analysis was carried out separately for normal controls and for C.N. in the following analysis, performed in an analogous way to Experiment 1.

Control Subjects. Mean percentages of correct responses for normal subjects are presented in Figure 5. As in Experiment 1, the data were analysed by items as the random factor with the response on the relevant

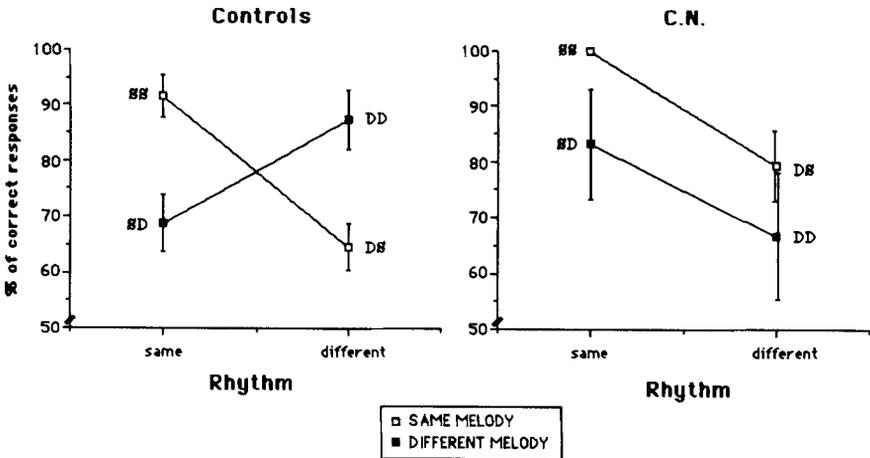


FIG. 5. Mean percentages of correct responses for each type of response as a function of the presence of melodic irrelevant changes obtained by controls (left panel) and C.N. (right panel) in Experiment 2. Vertical bars indicate ± 1 SD.

rhythmic dimension (same vs. different) and the irrelevant melodic manipulations (S vs. D) as factors. The score associated with each item was the sum of the responses given by the subjects, thus allowing for a maximal score of four correct responses per item. This analysis yielded a rhythm \times melody interaction, $F(1, 44) = 33.6$, $p < 0.001$. As can be seen in Figure 5, the presence of melodic changes improved performance on the "different" responses, $F(1, 22) = 14.01$, $p < 0.001$, whereas it interfered with the "same" responses, $F(1, 22) = 20.3$, $p < 0.001$. Accordingly, there was no global difference in performance between trials involving a melodic change (SD and DD) and trials without a melodic change (SS and DS; $F < 1$). It should also be added that every normal control displayed these interactive effects.

C.N. Mean percentages of correct responses obtained by C.N. are also presented in Figure 5. The same analysis as that performed on controls' scores was conducted on her data. The analysis yielded only a main effect of response to rhythm, $F(1, 44) = 4.56$, $p < 0.04$, and no interaction with melodic information ($F < 1$). As can be seen in the Figure, C.N. performed better on "same" trials than on "different" ones. However, C.N. appears to be influenced by the presence of a melodic change, although not in an interactive fashion—that is, she generally performed better on trials containing no melodic change (SS and DS) than on ones involving such changes (SD and DD). However, this trend failed to reach significance [$F(1, 44) = 2.76$, $p < 0.11$].

The lack of statistical significance was, at least partially, due to the high variability¹ of C.N.'s responses on trials involving melodic changes (SD and DD; standard deviations were 8.0 around a mean of 75.0% of correct responses), as opposed to the trials where there were no such changes (SS and DS) and on which she responded more confidently (with a standard deviation of 4.0 and a mean of 89.6%). This discrepancy in terms of variability was apparently not due to a ceiling effect on the latter type of trials. Her scores remained less variable on the "different" trials—where she generally performed more poorly—when there was no melodic change than when there was one (with 6.5 and 13.8 as standard deviations for DS and DD, respectively).

Discussion

The first conclusion to be drawn from the present experimental situation is that it was remarkably efficient in producing behavioural evidence of integration between rhythm and melody in the *normal* brain. Normal subjects exhibited response patterns that were clearly and systematically affected by the irrelevant melodic dimension, although decisional independence was promoted by explicitly instructing them to concentrate only on rhythm. If rhythm were perfectly separable, neither S nor D responses should have been affected by the presence of a difference in the irrelevant melodic dimension, because such a difference should be completely filtered out in the process. The fact that a large incongruity effect was found (that is, SS and DD were superior to SD and DS) indicates that rhythm and melody are not entirely separable, but, rather, are integrated at some level in the processing of musical information.

Integration of the two dimensions was further supported by the observation of a systematic relation between the rhythmic decision and the nature of the melodic manipulation. Indeed, insertion of a melodic change was found to improve discrimination of a rhythmic difference (DD was superior to DS), whereas it was found to interfere with rhythmic identity (SD was inferior to SS). The finding of such interactive effects suggests response competition and/or a decision conflict between the processing of the two dimensions.

Typically, the Stroop technique has been considered to measure integration, via interference, as a late effect, arising toward the response end of the information processing sequence (Dyer, 1973). This interpretation, however, has been seriously questioned in recent vision research. Current notions are that it does reveal interactions between dimensions that can occur anywhere in the system; that is, either early or late in processing (Melara & Marks, 1990; Pomerantz, Pristach, & Carson, 1989). Therefore,

¹We are particularly indebted to Mary Riess Jones, who brought this point to our attention.

it is at present difficult to infer the locus of integration in terms of processing stages from the presence of a Stroop effect. Nevertheless, its presence in the present study constitutes rather strong evidence of integration of melody and rhythm in the normal brain. As this evidence was precisely what had been expected from the present situation, we can now turn our attention to the question of whether or not, and to what extent, brain damage can fragment this unified experience.

C.N.'s response pattern is consistent with our premises that a cognitively well-localized brain lesion can produce disconnection-like behaviour between rhythm and melody. Indeed, C.N. did not exhibit any of the manifestations of integrated behaviour observed in normal subjects. She did not show incongruity effects, nor did she reveal interactive effects between the type of rhythmic decision and the content of the melodic manipulation in the present experiment. Moreover, her performance remained relatively accurate and constant across experiments, thus indicating little, if any, consideration of melodic variation. Thus, for her, melody and rhythm appear to be entirely separable dimensions.

Yet, there was one indication that C.N. was somewhat sensitive to melodic manipulations. In the present experiment, she tended to perform better when no melodic change was inserted (i.e. in SS and DS trials) than when one was presented (in DD and SD trials). This occurred regardless of the type of decision to be made. This observation suggests that melodic information could not be completely ignored, even though its content was not interpreted properly. Thus, for her, the situation might actually be considered more like a Garner (1974) task than a Stroop task. In Garner's task, interference is inferred when variation on the irrelevant dimension cannot be ignored, and thus it differs from Stroop effects, which indicate to what extent the content of the irrelevant variations can be ignored (Pomerantz, 1983; Pomerantz et al., 1989). The fact that C.N. appears to be indiscriminately affected by variations on the irrelevant dimension, instead of being sensitive to the content of these variations as being "same" or "different", is indicative of Garner interference. While suggestive, this possibility is weakened by two other aspects of the results. The interfering effect of melodic changes in C.N.'s responses was not statistically significant. Moreover, this lack of robustness was not random; it arose predominantly from her highly variable response mode to trials containing a melodic change as opposed to those that did not.

An alternative explanation is that her undifferentiated responses to melodic changes simply reflect the noisy output delivered by the damaged melodic system, against the background of an otherwise normally functioning system. In her case, melodic information should be subject to a considerable amount of noise, as a result of selective disturbance due to brain damage. The possibility that this internal noise increases, rather than

decreases, with the introduction of a melodic change is likely. Accordingly, all trials that appeared to increase such noise were less accurately judged than trials that did not create so much noise. This latter account has the merit of being both most consistent with C.N.'s neurological status and with her overall pattern of responses, which revealed a high degree of separability between rhythm and melody.

CONCLUSIONS

The present study was designed in an effort to clarify the issue of independence between melody and rhythm in the processing of musical information. To this end, we exploited neuropsychological dissociations, investigating a patient, C.N., who happened to suffer from a severe impairment of melody processing without an accompanying disorder of rhythm processing as a consequence of brain damage. The results from the present study seem to allow the following conclusions.

First, melody and rhythm appear to be the product of at least partially separate processing systems. This conclusion derives mainly from C.N.'s pattern of performance. She recurrently exhibited chance performance in the processing of melodic structure and normal performance in temporal structure processing, across different experimental settings. This pattern of results gave rise to the observation of a reversed association, when compared to that of normal controls (Experiment 1). Such a particular form of behavioural dissociation allows the rejection of the notion that rhythm and melody are processed jointly by a single system. Finally, separability of the two dimensions was further documented in C.N., having been tested in conditions where a normal working brain integrates both dimensions (Experiment 2).

Taken together, these results strongly support the notion that, at some level in the processing of musical information, melodic structure and temporal structure are treated independently. The basic idea here is that there must be a neural system that is more dedicated to the processing of melodic information than to temporal information, and that this system can be selectively impaired by brain damage. The implication of this rather standard inference from the behavioural study of brain-damaged patients is that neuropsychological data can impose further constraints in models that are proposed to explain normal functioning. In the present context, such a constraint bears on the single-component model, or the dynamic model, posited by Jones and Boltz (Boltz, 1989a; Jones, 1987). Following neuropsychological data, this model does not appear to be a likely architecture underlying the processing of melody and rhythm, at least in its strong version as an indivisible working system.

A second conclusion from the present study is that melody and rhythm are also not completely independent dimensions. Integration of the two

dimensions was indeed found to be quite easy to elicit in normal subjects. In Experiment 2, control subjects were required to judge rhythmic identity of two sequences when their melodies were either the same or different. Accuracy of judgements was systematically affected by the content of the melodic variations, which failed to be ignored. This finding implies that a completely independent model for the processing of rhythm and melody is no more tenable than is a single-system model.

The fact that integration takes place in normal subjects is not at odds with the notion of early separation of melody and rhythm. C.N.'s results do lead to the prediction that evidence of perceptual independence should be found in normal subjects for melody and rhythm, as long as it is the early processing stages that are tapped. Yet, this claim remains to be demonstrated empirically. At least in the visual domain, some evidence has been found that dimensions described as integral by standard criteria, such as using those of Garner, have to be considered as separable when using a more indirect criterion of separability (Kolinsky, 1989), such as the occurrence of illusory conjunctions (Treisman, 1986; Treisman & Schmidt, 1982). Further exploitation of these concepts and methods in the music domain is certainly worthwhile, for its usefulness has been fully demonstrated in the present study.

Finally, to claim that integration takes place after early separation raises the question of the nature of the integrated representation. Concluding that melody and rhythm are integrated somewhere in the building of a musical representation of a sequence has only indirect bearing onto the format of the resulting integrated construct. This proposal is equally compatible with the possibility that formerly separable dimensions are then fused into a new, higher-order code. But it is also compatible with the alternative: that is, that the two dimensions maintain separate representations with new associative links. Distinguishing between these two possible formulations should be the goal of future enquiry.

In summary, we were able to show that neuropsychological dissociations can provide a means of teasing apart normally interacting systems. This logic was successfully applied here to the processing of melodic and temporal patterns in music discrimination. The fact that the type of structural manipulations and the paradigms considered here were of a general nature, being inspired from vision research, may add some generalizability to the present findings. It is likely, for instance, that the present methodology may shed similar light onto the processing of interacting dimensions other than musical ones, such as prosody and speech. Within the musical domain, the present research can be regarded as a first step towards specifying the boundaries of separability between melody and rhythm. Future research should aim at elucidating the boundaries by systematically studying each dimension at different levels of elaboration. This may help to clarify the locus and the nature of integration effects in musically defined terms.

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