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Effects of a Change in Instrumentation on the Recognition of Musical Materials

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The present study investigates the effect of a change in instrumentation on the recognition of musical excerpts in Western contemporary and tonal music. The critical finding was a strong effect of timbre on the recognition of musical material that is modulated by both the extent of musical expertise and the musical style. Changing the instrumentation of musical excerpts from a piece by Reynolds considerably hampers recognition among musicians (Expts. 1 and 2), but not among nonmusicians, whose recognition was poor regardless of instrumentation. Both musicians and nonmusicians were affected by instrumentation change in excerpts from a symphonic poem by Liszt (Expt. 3). This finding suggests that timbre may contribute, along with pitch and rhythm, to the identity of musical materials. The difference found between musicians and nonmusicians with the Reynolds piece may be parsimoniously explained by the fact that the musicians were considerably more familiar with contemporary music than were the nonmusicians.

The purpose of the present study was to investigate the effect of a change in instrumentation on the recognition of thematic materials used in Reynolds's *The Angel of Death*. In this piece, five themes are first

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presented with one instrumentation (either piano or orchestra) and then, later in the piece, they occur again with a different instrumentation (see Reynolds, 2004). There is a kind of mirror relation between the performances of the orchestra and the pianist. This mirror relation allows the listeners to reverse their musical perspectives and to listen differently to a piece with the same musical structure. As such, recognition of similar materials with a change in instrumentation would contribute to the establishment of formal relations within the piece, if the timbre change did not hinder recognition. The main question was to investigate whether it would be difficult for participants to recognize these themes in the context of the piece (see McAdams, Vines, Vieillard, Smith, & Reynolds, 2004) when they reoccurred with a different instrumentation. This issue also provided the opportunity to address whether timbre potentially contributes, along with pitch and rhythm, to defining the identity of musical materials. This means that timbre may be a basic component of material identity, similarly to the way facial expressions contribute to the perceptual identity of a person. In the history of Western music, the quality of timbre that results from instrumentation was considered as less important than other form-bearing dimensions such as pitch and rhythm. For example, in the baroque period, the instrumentation required to perform a given piece was generally open, or at least weakly constrained. This suggests that the musical quality of the musical material was mostly defined by the combination of pitch, duration, and loudness.

The importance of instrumentation increases considerably in the classical and romantic periods, as attested notably, by the publication of several textbooks on instrumentation (see Berlioz, 1843; Gevaert, 1885; Guiraud & Busser, 1933; Kastner, 1837; Koechlin, 1944; Rimski-Korsakov, 1913/1964). Also several transcriptions of orchestral pieces for other instruments (e.g., the piano) have been done (see, e.g., Liszt's transcriptions of Beethoven's symphonies and Berlioz's *Symphonie Fantastique*). No one would contest that these transcriptions are generally less referential than the pieces as they were composed with their original orchestration (with maybe one exception for Moussorsky's *Pictures at an Exhibition*). From the early 20th century, composers—notably French composers such as Debussy, Ravel, Koechlin, Varèse, Jolivet, and Messiaen—paid a great deal of attention to timbre and acoustic phenomena. Timbral qualities turned out to be of critical importance in contemporary music, where timbre was supposed to act as a potential form-bearing dimension that might replace, accompany, or interact with the pitch and duration dimensions (see Barriere, 1991; Erickson, 1976; Lerdahl, 1987; McAdams, 1987; Slawson, 1985). Along this line, we might expect that a change in instrumentation, which affects the quality of timbre, would have considerable effect on listeners' ability to recognize the the-

matic material. Our goal was to investigate the strength of this effect in the context of contemporary music, which puts great emphasis on timbral qualities.

From a psychological point of view, this issue also allows for the study of how different sound dimensions are combined. Music conveys information over a number of perceptual dimensions simultaneously, such as pitch, loudness, duration, and timbre, which McAdams (1989) has referred to as form-bearing dimensions. The question of whether these dimensions are processed separately or in an integrative way remains an open question for music psychologists (see Peretz & Kolinsky, 1993, for a debate). Several studies have investigated with perceptual tasks how pitch and timbre are combined. For example, Crowder (1989) found an influence of timbre on pitch judgments. Participants had to make same/different judgments concerning the pitches of two successive tones. The two tones were played on either the same instrument or on different instruments. Pitches were judged faster and more accurately as being the same when they were played on the same instrument than when they were played on different instruments. Likewise, by using rapid classification tasks in the tradition of Garner (1974), Melara and Marks (1990a, 1990b, 1990c) also observed an interaction between pitch and timbre in individual tones. Pitt and Crowder (1992), by varying pitch and timbre orthogonally, provided additional evidence in favor of an interaction between both dimensions. The listeners had to judge whether the second of two sequentially presented tones had the same pitch as the first. The timbres of the first and second tones were either the same or different. The results showed that the listeners had no difficulty answering "same" when both pitch and timbre are the same for the two tones. However, when the timbre of the second tone was changed, performance decreased significantly. This result suggests that timbre influences the perception of pitch. In addition, Krumhansl and Iverson (1992, Expt. 1) also used the standard Garner (1974) classification tasks to evaluate how pitch and timbre interact at the level of individual tones. The results showed that the participants could not attend to the pitch of a tone without being influenced by its timbre and could not attend to the timbre of a tone without being influenced by its pitch.

It is worth noting that the influence of timbre on pitch perception seems to depend on the degree of musical expertise. Beal (1985) asked listeners to judge whether two chords played with different timbres were the same or different. Nonmusicians found it very difficult to judge two chords as being the same when they were played with different instruments, although they performed well when the chords were played on the same instrument. Musicians were more accurate overall, even if they found it more difficult to judge the chords as identical when they were played with

different timbres. Furthermore, Pitt and Crowder (1992) found that when a pitch was played with different timbres, it was very difficult to judge it as being the same pitch, but in addition, the degree of difficulty depended on musical training. Indeed a supplementary analysis of the same-pitch/different-timbre data revealed a bimodal distribution of accuracy that correlated with the musical background of the participants. In their Experiment 3a, Pitt and Crowder (1992) found a similar result, with accuracy in pitch discrimination being 15% higher for the musicians than for the nonmusicians. It was proposed that for nonmusicians, timbre is likely to be a more salient dimension than pitch because it is generally more informative about environmental events, and the nonmusicians have not been trained to analyze pitch closely. Another explanation may be that timbre, which is a salient surface characteristic of musical tones, would be more influential for nonmusicians than for musicians. This assumption would be in accordance with the results observed in the research on the effects of expertise. Experts seem to build a representation of the material based on the deep structure of the stimuli (as well as on surface features), whereas the perceptual representation of novices would be based only on the surface features. The current literature leads one to expect that nonmusicians would be more influenced by the timbre of a musical excerpt than by its harmonic structure.

Other studies have investigated how timbre and pitch combine in memory, a question that is central to the present study. Semal and Demany (1991) reported results supporting the idea that pitch memory is independent of the timbre of context tones. They used the pitch-recognition paradigm of Deutsch (1972). In this paradigm, two tones (standard and comparison) are judged as same or different. A number of intervening tones were presented between the standard and comparison tones. Semal and Demany (1991) varied the period (close versus remote from the period of the standard tone) and the spectral content (same versus different harmonic content as the test tones) of the intervening tones. They found that intervening tones close in pitch to the standard and comparison tones produced memory interference. In contrast, they found no effect of similarity in timbre of the intervening tones on memory performance for pitch. The latter result suggests that pitch memory is independent of the timbre of context tones. Krumhansl and Iverson (1992, Expts. 2 and 3) had a similar approach to that of Semal and Demany (1991). They also found independence between pitch and timbre. Changing the pitches of the tones surrounding the target tone did not interfere with memory for a target timbre, and changing the timbres of tones surrounding the target tone did not interfere with memory for a target pitch. They also showed that memory for the target pitch was not different when the timbre varied than when it was constant. Taken together, these results suggest that pitch memory is little affected by timbral variations.

In contrast to these simple stimuli, studies using memory for melody supply different results suggesting that timbre may be encoded in an episodic trace and may influence subsequent recognition. Radvansky and Potter (2000), for example, showed that timbre might act in terms of source cuing. Source cuing is a source-monitoring process in which the retrieval of a memory trace is aided by the use of a memory probe that includes information indicative of the original source (an episodic memory process[1]). Melodies were presented to participants who had to identify which of two melodies (target or distractor melody) had been heard earlier. They manipulated two variables: a Match/Mismatch condition referred to whether or not the *target melody* had the same timbre as the original melody, and a Same/Different condition referred to whether or not the *distractor melody* had the same timbre as the original. The participants were more accurate when the timbre of the target melody matched the original than when it mismatched. Their findings also showed that timbre was more indicative of the source than pitch. In addition, Peretz, Gaudreau, and Bonnel (1998, Expt. 3) corroborated the hypothesis in which timbre influences the recognition of melody. They expected that changes in surface properties between study and test melodies would influence performance in an aesthetic preference task (rating the liking of melodies) and have little impact on recognition performance, because the affect is proximal to the perceptual processing system whereas recognition is considered to tap into more abstract forms of memory. To evaluate this hypothesis, they modified the instrument on which the melodies were played. However, contrary to their hypotheses, they observed a strong effect of timbre change on melody recognition. Melodies that remained in the same timbre from study to test were recognized better than were old melodies that were different in timbre at study and test. In a fourth experiment, they also demonstrated that the timbre of the studied melody is part of the episodic record and is thus available for subsequent recognition. In addition, they suggested that timbre may be computed automatically and may be critical to episodic memory for melodies. These last two experiments (using more complex stimuli than just pitch) therefore suggest that timbre may be stored as contextual information for the presented melody, so as to confer to the studied event a distinct episode-like quality. Timbre and pitch would thus be computed separately and linked together in episodic memory, so as to provide a unified recollection of the studied event.

1. *Episodic* memory is generally opposed to *semantic* memory. The distinction between these two memory systems has been described in detail by Tulving (1972). Episodic memory is concerned with storage and retrieval of temporally dated, spatially located, and personally experienced events or episodes, and temporal-spatial relations among such events. Semantic memory is concerned with storage and utilization of knowledge about words and concepts, their properties, and interrelations.

The influence of timbre on memorization of musical material was also shown to depend on the extent of musical expertise. Wolpert (1990) found differences in pitch and timbre processing in nonmusicians and musicians, suggesting that timbre is more salient than pitch in nonmusicians. In her experiment, the participants performed an XAB match-to-sample task. They had to judge whether melody A or B was more like melody X. One of the two comparison melodies was always melody X played with a different timbre. The other comparison melody was either a different melody with the same timbre as melody X or was played with a harmonic accompaniment transposed to the dominant key (i.e., there was a key mismatch between melody and accompaniment). While the musicians unanimously chose the same melody and accompaniment as melody X (ignoring the timbre difference), only half of the nonmusicians consistently did so. The remainder matched on the basis of timbre a portion of the time. However, these findings have been questioned by Radvansky, Fleming, and Simmons (1995), who attempted to replicate and extend the results observed by Wolpert (1990) by controlling the clarity of the instructions. Listeners were presented with a melody and then later asked to identify which of two alternatives (target vs. distractor) corresponded to the original melody. In the Match condition, the target melody was in the same timbre as the original, whereas the distractor was in a different timbre. In the Mismatch condition, the target melody was in a different timbre whereas the distractor was in the same timbre as the original. In their second experiment, they compared musicians and nonmusicians and found that both groups were similarly affected by timbre changes: more errors were made in the Mismatch condition than in the Match condition. As a consequence, the influence of timbre on memory for musical stimuli as a function of musical expertise remains a matter of debate.

In sum, studies using single tones as stimuli provide evidence that pitch and timbre are stored independently in memory. By contrast, studies using longer melodies provide evidence that both dimensions are integrated in memory. Finally, some studies suggest that this issue may be modulated by the extent of musical expertise. It should be noted that none of the current published studies addresses this issue with realistic musical materials drawn from contemporary music. Some studies, however, have addressed the recognition of contemporary musical excerpts. For instance, in Krumhansl (1991), participants were able to recognize excerpts despite changes in contour, pitch height, duration, dynamics, and interval size. However, no change in timbre was performed in this study, because all stimuli were played on the piano. The question therefore remains concerning whether change in timbre will produce detrimental effects on recognition of musical materials.

According to the results of previous studies, we assumed that timbre would influence the subsequent recognition of musical excerpts and that this effect would be modulated by the extent of musical expertise, even if this issue remains a matter of debate. To the best of our knowledge, the present study is the first to address this question with realistic musical material drawn from contemporary music. A crucial point is that the change of instrumentation was performed by the composer (and not by the experimenter). With complex musical excerpts, it is not conceivable to change the timbre of the excerpts in an automatic way by artificially assigning a given tone to a given timbre. Orchestration requires considerable "savoir-faire," without which the result would be musically incoherent. The risk would then be that participants fail to recognize excerpts not because of the change in timbre, but simply because the performed change in instrumentation would result in a weakening of the musical coherence of the excerpt. As described by Reynolds (2004; see also McAdams, 2004), a change in instrumentation raised a number of difficulties that the composer had to solve. As such, the musical themes were of different instrumentation while containing the same type of musical qualities. Another advantage results from the fact that the experimental stimuli were also performed and recorded under the control of the composer. That is to say, both the pianist and the orchestral conductor performed expressive deviations in their playing that were commented on by the composer so that both versions of the theme remained fairly comparable for musical expressiveness, irrespective of change in instrumentation. Because of these controls, it was of interest to address whether musically trained and untrained listeners would be able to recognize the Reynolds themes under change in instrumentation.

Experiment 1: Contemporary Musical Materials

METHOD

Participants

Seventy-three volunteer students participated in this experiment: 29 students from an introductory psychology course at the Université de Bourgogne, with no formal training in music (referred to hereafter as *nonmusicians*), and 44 candidates for the final diploma of several French conservatories (referred to hereafter as *musicians*). The musicians at this level of expertise were quite familiar with contemporary music, and they actively participated in playing contemporary pieces. All participants either received course credit or were paid 7€ for their participation.

Stimuli

Thirty-six musical excerpts were drawn from the original thematic materials of *The Angel of Death* (cf Reynolds, 2004): 18 were played on the piano and 18 others were the

same excerpts played by a chamber orchestra. A list of the excerpts (theme, subsection(s), durations of the piano and orchestra versions) is given in Table 1.[2] The sound stimuli were originally recorded in IRCAM's Espace de Projection concert hall for the piano versions and in the University of California at San Diego's Studio A for the orchestral versions. The digital recordings were edited with SoundEditPro software at CD quality (16 bits and 44.1 kHz).

Apparatus

The experiment was run with PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) on a Macintosh Powerbook G3 computer. The musical excerpts were amplified by a Luxman A357 power amplifier and then presented over Sennheiser HD 200 headphones.

Procedure

The experimental procedure was split into two phases. In the first (learning) phase, the participants were asked to carefully listen to nine excerpts played either by the piano or by the orchestra. The participants were informed that following the learning phase, there would be a recognition test. In the second (recognition) phase, participants had to recognize these nine excerpts played with nine other excerpts from the same piece. These 18 excerpts (old and new) were played either by the piano or by the orchestra. In two conditions, the timbre of the excerpts presented in the second phase was the same as that in the first phase. In the two other conditions, the timbre was different. A different group of participants ($7 \leq N \leq 11$) performed each of the four conditions for each group of Musical

TABLE 1
Description of the Stimuli Used in Experiment 1

	Duration (s)	
Excerpt	**Piano**	**Orchestra**
T 1.1-2-3	21.4	21.3
T 1.1-5	17.8	17.0
T 1.6-7	16.8	12.9
T 1.9	15.4	14.3
T 2.1-2	17.5	14.5
T 2.4	11.0	10.3
T 2.5-6-7	17.0	17.5
T 3.2-1	14.4	17.3
T 3.3-4	11.0	14.1
T 4.1-2-3-4	15.4	13.8
T 4.5-6	11.0	10.1
T 4.7	11.8	9.9
T 5.1	29.1	30.4
T.5.2	12.3	12.3
T 5.3	16.6	15.6
T 5.4	29.3	30.5
T 5.5	22.7	20.4
T 5.6-7	21.3	25.1

NOTE—Excerpt labels are of the form <Theme.subsection(s)> (e.g., T1.6-7 includes subsections 6 and 7 of Theme 1).

2. The stimuli for this study may be found on ftp://ftp.ircam.fr/private/pcm/angel/instrumentation_format.zip where "format" should be replaced with "wav" or "aiff" according to the preferred sound-file format.

Expertise. In the two conditions using a different timbre in the second phase, participants were informed by the experimenter just before the recognition phase that a change in timbre (instrumentation) occurred and that now all the excerpts (those presented in the learning phase and the new ones) would be played either by the piano or the orchestra according to the condition. The participants had to indicate for each musical excerpt whether they had heard it during the learning phase, irrespective of the change in instrumentation. The participants were encouraged to respond as soon as they were sure of their response by pushing one of the keys "yes" or "no" on the keyboard. These requests were printed on the screen for each excerpt.

Design

There were three between-subjects independent variables: Musical Expertise (musicians vs. nonmusicians), Timbre Change (same-timbre vs. different-timbre), and Instrumentation (piano vs. orchestra in the learning phase). Percent correct recognition was the dependent variable.

RESULTS

Figure 1 displays mean percent correct recognition scores as a function of musical expertise for the four experimental conditions. The data were analyzed with a Musical Expertise (2) × Timbre Change (2) × Instrumentation (2) between-subjects analysis of variance (ANOVA). There was a significant main effect of Timbre Change with greatest performance in the same-timbre compared to the different-timbre conditions, $F(1,65) = 14.56$, $p = .0003$, $MSE = 138.93$. This effect was modulated by the extent of Musical Expertise, as shown by the significant two-way interaction, $F(1,65) = 15.55$, $p = .0002$, $MSE = 138.93$. None of the other effects were significant. Tukey-Kramer post-hoc comparisons ($p < .05$) confirmed that the same-timbre conditions for musicians were significantly higher than all of the other conditions, which were not significantly different from one another. However, exact binomial tests showed that the mean performance of nonmusicians was significantly higher than chance whether the timbre changed or not. Only the mean performance of the musicians in the different-timbre condition did not significantly differ from chance.

A signal-detection analysis of the data exactly mirrored the results of the preceding analyses. Responses were considered as hits when the participants responded "yes" to an excerpt presented in the first phase and as false alarms when they responded "yes" to an excerpt not presented in the first phase. From these rates, the d' measure of sensitivity was computed for each participant using a yes/no model (Macmillan & Creelman, 1991). There was a main effect of Timbre Change with greatest sensitivity to differences between old and new excerpts in the same-timbre compared with the different-timbre conditions, $F(1,65) = 16.63$, $p < .0002$, $MSE = 0.49$. This effect was modulated by the extent of musical expertise, as shown by the significant two-way interaction, $F(1,65) = 15.60$, $p < .0002$, $MSE =$

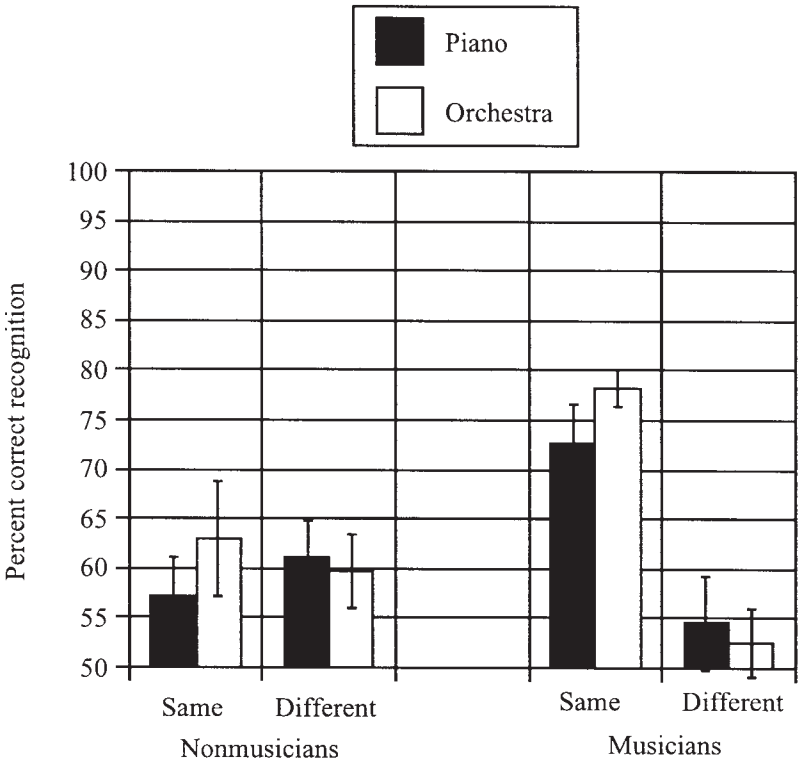

Fig. 1. Experiment 1. Percent correct recognition obtained with contemporary excerpts as a function of instrumentation in the learning phase, musical expertise, and timbre change.

0.49. An analysis of the response bias index β revealed only a two-way interaction between Musical Expertise and Timbre Change, $F(1,65) = 5.23$, $p < .05$, $MSE = 0.64$. The musicians responded "no" significantly more often in the same-timbre condition compared to the different-timbre condition and to both conditions for the nonmusicians.

DISCUSSION

The critical point of the experiment was to assess whether timbral qualities linked to the difference in instrumentation would be incorporated into the memory trace of contemporary musical excerpts. The detrimental effect of timbre change on recognition for musicians demonstrates that timbre qualities are indeed integrated into this trace, because performance deteriorates drastically when the instrumentation changes between the memorized excerpt and the to-be-recognized excerpt, even though listeners were instructed to ignore such changes. It is remarkable, in fact, that musicians performed at random in the timbre change condition, suggest-

ing that for this group, timbral features are of great importance in contemporary music.

Before elaborating more on this finding, it was necessary to check that the performance levels of musicians in Experiment 1 did not reflect a conscious strategy on their part to memorize the most salient features present in this style of music. In Experiment 2, to prevent the use of such memorization strategies, and contrary to Experiment 1, musician listeners were not informed that there would be a recognition test after the learning phase. Only the conditions orchestra-orchestra versus orchestra-piano were tested in this experiment because the effects of instrument change were parallel for both instrumentations in Experiment 1.

Experiment 2: Contemporary Materials with an Unexpected Recognition Phase

METHOD

Participants

Seventeen candidates for the final diploma of several French conservatories (referred to below as *musicians*) participated in the experiment and were paid 7€. The musicians at this level of expertise were quite familiar with contemporary music, and they actively participated in playing contemporary pieces.

Apparatus, Stimuli, and Procedure

Experiment 2 was identical to Experiment 1 except that the participants were not informed that there was a recognition phase that would follow the learning phase, and learning was limited to the orchestral versions of the materials. Listeners were instructed that they would perform a task judging the pleasantness of contemporary musical excerpts. They listened to the nine test excerpts and had to indicate on a seven-point scale how pleasant each one was. Only when they had finished were they informed that there would be a subsequent recognition phase. There were two conditions using different instrumentations. The participants in the timbre-change condition were instructed that a change in instrumentation would occur and that now all the excerpts (those previously presented in the learning phase and the new ones) would be played by the piano. They were instructed to ignore the instrumentation change in making their judgments.

RESULTS AND DISCUSSION

The results are quite similar to those obtained in Experiment 1, namely 80% of correct recognition in the orchestra-orchestra condition ($N = 8$) and 55% in the orchestra-piano condition ($N = 9$). Performance decreased drastically in the orchestra-piano condition compared with the orchestra-orchestra condition, $F(1,15) = 18.07$, $p = .0007$, $MSE = 145.60$. d' values were computed from hit and false alarm rates, and the results completely mirrored the effects revealed with percent-correct scores. The sensitivity to

differences between old and new excerpts decreased in the orchestra-piano condition compared with the orchestra-orchestra condition, $F(1,15) = 17.90$, $p < .0008$, $MSE = 0.59$. No significant effect was observed for the response bias index, suggesting that the criterion used by the participants was the same for both conditions. The findings of Experiment 1 would thus not seem to result from a conscious strategy adopted by musicians when memorizing contemporary music. It seems that when listening to this kind of complex music, musicians naturally pay attention to and perceive the timbre as a structure of interest, and this leads to an integrated encoding of the timbral features or dimensions. As a consequence, in this second experiment, the musicians were still perturbed when the timbre changed in the recognition phase, leading to worse performance.

Taken together, Experiments 1 and 2 point to an important effect of timbre on the recognition of musical material that is strongly mediated by the extent of musical expertise. One parsimonious way to interpret this effect is that contemporary musical pieces were processed differently as a function of the level of musical expertise. Musically trained listeners were more familiar with this type of music, and it is likely that they possessed abstract schemata to encode contemporary music. As a consequence, musicians probably retained some of the characteristics of the musical excerpts, even though they did not know that a recognition test would be performed later (Experiment 2). Nonmusicians were not influenced in the same way by timbral characteristics in Experiment 1, primarily because their performance levels were only just above chance in the no-timbre-change condition. Musically untrained participants were definitely not familiar with contemporary music. The abstract schemata underlying Western tonal music differ from those of contemporary music, which relate more to surface discontinuities created by changes in melodic contour, loudness, and irregular rhythm. These surface discontinuities were likely to be more astonishing for musically untrained listeners, who were likely to be fascinated by the novelty created by rhythm, loudness, timbre, and pitch structures. They did not possess the abstract schemata necessary to encode these characteristics. So even if they performed above chance, their performance levels were quite low even for the no-timbre-change condition, not leaving much room for an effect of timbre change to manifest itself. However, it is worth noting that if timbre were an important cue for their memory of contemporary music, one might expect their performance to decrease to chance levels in the timbre-change condition, whereas their mean was still significantly higher than chance according to an exact binomial test.

Therefore, the difference observed between musicians and nonmusicians could be due to a more or less greater familiarity with the contemporary musical style. This post hoc interpretation was investigated further

in the next experiment, by using Western tonal-metric music, which is more familiar to both groups of listeners. We assumed that recognition performance with tonal excerpts would be globally better than that of the contemporary excerpts because the listeners are more familiar with the former, particularly as concerns the underlying scales, harmonies, and metric organization. We also expected that nonmusicians should now be more influenced by the change in timbre resulting from the change in instrumentation.

Experiment 3: Western Tonal Materials

Finding a tonal/metric piece that lends itself to studies analogous to those performed with *The Angel of Death* was not an easy choice. Strong constraints led to the choice of Franz Liszt's *Symphonic Poem #3, Les Préludes* (1851–1854/1977) (Gut, 1989; Walker, 1993). Because Reynolds's work is written for piano and orchestra, it was tempting to consider keyboard concertos. But a piano concerto already poses the problem of the distribution and transformation of material between piano and orchestra within the piece itself, *before* any comparison is introduced. The composer has already made the choices. We preferred therefore to select a piece that was entirely written for orchestra, but for which there existed an adaptation for keyboard.

The duration of the Liszt piece, about 17 minutes, corresponds to that of each part (Sectional or Domain) of the Reynolds piece (see Reynolds, 2004). But duration is not a sufficient criterion. The piece must be written as a single block, all the while containing well-delimited sections. This is the case with the Liszt piece (see the formal schema in Fig. 2), which also respects a criterion of formal complexity: *Les Préludes* does not limit itself to a sonata form, which would be too obvious and inadequate for our needs. It has a well-designed plan that preserves the formal functions of exposition, development, and recapitulation without the corresponding sections being simply contiguous. A transition with three subsections is inserted between the exposition and the development. Between the development and the recapitulation, Liszt has placed an *allegretto pastorale* with a very different character in which a third theme appears. If we assimilate the piece to a large-scale unitary form that groups the different movements of a whole sonata into a single block, this *allegretto* assumes the place of the traditional scherzo (as indicated in Fig. 2). The presence of this section taxes a listener's memory: it introduces a contrast in the continuity of the work, before the return of the two "love" themes that take on a surprising martial demeanor in the recapitulation, because Liszt modified the rhythm, the tempo, and the timbres.

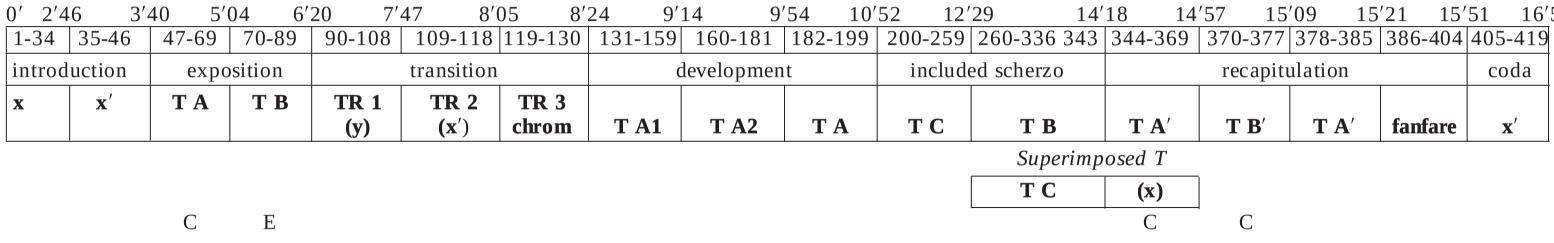

Fig. 2. Formal schema of the Liszt *Symphonic Poem #3, Les Préludes*, with timings, measure numbers in the score, sectional structure, and thematic structure. The timings are based on the Deutsche Grammophon CD 447 415-2, Berliner Philharmoniker, dir. Herbert von Karajan, re-release of the original LP on Polydor International GmbH, Hamburg, 1968. T = theme, TR = transition.

It is precisely the subtlety of the motivic and thematic transformations and the richness of the web of relations that constitute the last criterion of choice. The two love themes have motivic links, and Liszt does not hesitate to perform melodic and rhythmic transformations with a high degree of perceptual interest. In spite of the gap in esthetic intent and the obvious differences in materials and compositional method, Liszt's *Les Préludes* and Reynolds's *The Angel of Death* have a sufficient number of common qualities to justify studying them in parallel in an experimental framework.

METHOD

Participants

Seventy-six volunteer students participated in this experiment: 39 students from an introductory psychology course at the Université de Bourgogne, with no formal training in music (referred to below as *nonmusicians*), and 37 candidates for the final diploma of several French conservatories (referred to below as *musicians*). All participants either received course credit or were paid 7€ for their participation.

Stimuli

Thirty-six musical excerpts were drawn from *Symphonic Poem #3, Les Préludes,* by Liszt: 18 were played by the piano, and the other 18 were the same excerpts played by the orchestra. Table 2 lists the score references and durations of the excerpts.[3] The excerpts were extracted digitally from commercial CD recordings: Prague Piano Duo, Zdenka and Martin Hrsel, pianos, PRD 250 105 Harmoni Mundi for the piano version, and Berliner Philharmoniker, conducted by Herbert von Karajan, Deutsche Grammophon 447 415-2 for the orchestra version.

Procedure, Apparatus, and Design

The procedure, apparatus, and experimental design were identical to those described in Experiment 1.

RESULTS

Figure 3 displays percent correct recognition as a function of musical expertise for the four experimental conditions. These percentages were analyzed with a Musical Expertise (2) × Timbre Change (2) × Instrumentation (2) between-subjects ANOVA. There was a significant

3. To be sure that the length difference between the piano and orchestra versions of the same excerpts cannot account for the performances of the listeners, analyses were performed to correlate the absolute value of the difference in length of each pair of excerpts with the mean performance of the participants for each excerpt. We averaged the means of both musicians and nonmusicians because their patterns of results were highly similar in this experiment. The correlations were not significant, $r(18) = -.21$ and $r(18) = .20$, for the orchestra-piano and piano-orchestra conditions, respectively.

TABLE 2
Description of the Stimuli Used in Experiment 3, Drawn from Liszt's *Symphonic Poem #3, Les Préludes*

Excerpt		Duration (s)	
Measures	**Score Pages**	**Piano**	**Orchestra**
7-10	2	17.0	19.9
12-18	2	25.5	30.0
25-24	5-7	27.1	45.1
35-44	8-12	30.8	42.3
47-50	14	16.9	16.2
63-66	16	21.0	16.9
69-73	17-18	19.8	16.8
118-131	26-28	27.1	23.5
131-136	28-29	10.5	8.9
144-149	32-34	9.4	8.3
155-160	36	9.8	9.7
173-180	41-42	19.5	14.8
201-213	45	17.1	21.4
237-242	47	7.2	8.8
336-344	63-65	12.9	11.1
346-356	65-67	21.2	15.9
355-363	66-67	15.4	11.6
370-377	69-71	15.2	12.5

NOTE—Measure and page numbers refer to the Eulenburg edition of the orchestral score.

main effect of Timbre Change, with poorest performance in the different-timbre conditions, $F(1,68) = 61.94$, $p < .0001$, $MSE = 109.34$. In addition, across groups of participants, when a timbre change occurred in the recognition phase, scores were lower for a change from piano to orchestra than for a change from orchestra to piano, as shown by a significant Timbre Change × Instrumentation interaction, $F(1,68) = 7.90$, $p < .007$, $MSE = 109.34$. Finally, and contrary to Experiment 1, significantly higher recognition scores were observed across conditions for musicians compared with nonmusicians, $F(1,68) = 21.75$, $p < .0001$, $MSE = 109.34$. Tukey-Kramer post-hoc comparisons ($p < .05$) on the Timbre Change × Musical Expertise interaction were performed to parallel those with the nontonal materials in Experiment 1. Different-timbre conditions resulted in lower scores than same-timbre conditions for both musicians and nonmusicians. Although both groups had equivalent scores when the timbre changed, musicians had higher scores when there was no timbre change. So the effect of timbre change is still stronger for musicians than for nonmusicians with tonal materials.

Similar analyses performed on d' values show a significant main effect of Timbre Change with poorer sensitivity for the different-timbre than for the same-timbre condition, $F(1,68) = 66.91$, $p < .0001$, $MSE = 0.48$. The Timbre Change × Instrumentation interaction was significant, $F(1,68) = 7.85$, $p < .007$, $MSE = 0.48$, showing that sensitivity to differences

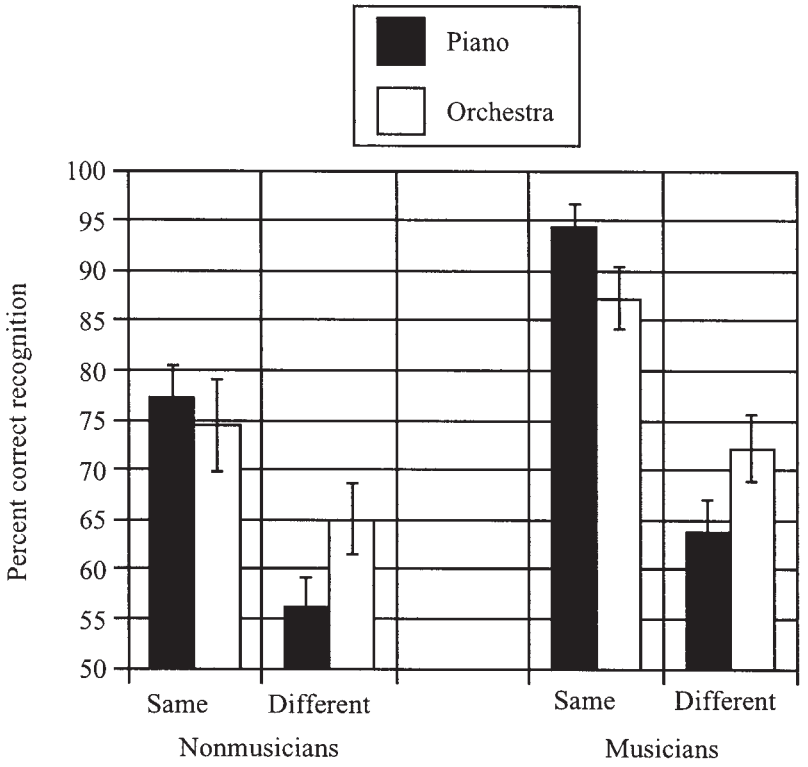

Fig. 3. Experiment 3. Percent correct recognition obtained with tonal excerpts as a function of instrumentation in the learning phase, musical expertise, and timbre change.

between old and new excerpts was lower in the piano-orchestra than in the orchestra-piano condition. This analysis also reveals the significant main effect of Musical Expertise, with greater sensitivity in musicians than in nonmusicians, $F(1,68) = 25.88$, $p < .001$, $MSE = 0.48$. Finally, the only difference with our previous percent-correct analyses is a significant interaction between Musical Expertise and Timbre Change, $F(1,68) = 5.56$, $p < .05$, $MSE = 0.48$, showing that musicians had higher sensitivity when there was no timbre change as revealed by a post-hoc comparison. No significant effect is observed for the response bias index, suggesting that the response criterion used by the participants was the same for both conditions.

DISCUSSION

The results of this last experiment show an effect of timbre that interacts with musical expertise only when d' is used as the dependent variable. Post-hoc analyses on both dependent variables show, however, that the

interaction is due to higher recognition rates in musicians than in nonmusicians in the same-timbre conditions, and to similar rates for both groups in the different-timbre conditions. This finding strongly suggests that timbre qualities are part of the memory trace of musical materials even in a musical style in which pitch and duration structures predominate and even when the instructions are to ignore changes in such qualities. The critical point of Experiment 3 was to suggest that the weak sensitivity to timbre found in nonmusicians in Experiment 1 was stylistically specific due to their unfamiliarity with the contemporary music. The musicians familiar with the contemporary musical style would possess the schemata necessary to encode some of the characteristics present in Reynolds excerpts and recognize them in a subsequent test. Timbre was also integrated into the memory trace and led to lower performance levels when instrumentation was changed in the recognition test. The nonmusicians, unfamiliar with contemporary music, would not possess the necessary schemata to encode the characteristics present in the Reynolds excerpts, and they obtained globally low performance levels (even if above chance) that did not leave much margin to reveal the influence of timbre.

Finally, it was rather astonishing to find that musically trained participants continued to be as sensitive to the timbre change in Experiment 3 with tonal materials as they were in Experiments 1 and 2 with contemporary materials. Timbre is not generally considered as a major form-bearing dimension in Western tonal music, for which harmonic, rhythmic, and thematic characteristics traditionally define the major structures of interest. This finding suggests that the psychological importance of timbre in Western tonal-metric music may have been underestimated and should be considered carefully.

It should be noted, however, that the surprising performance of musicians may also be caused, at least in part, by the fact that the change in timbre was instantiated by two different, unrelated performances of Liszt's *Symphonic Poem*. It was only possible to use performances available on commercial CDs for this experiment. Naturally, the performers, pianist, and conductor did not record the pieces in collaboration in a supervised manner in order to make both performances consistent along several parameters (including tempo, musical character, phrasing, and so on). These differences in performance were inevitably confounded with the instrumentation change. Although this may explain why participants were so sensitive to a change in instrumentation (partially confounded with a change in interpretation), the present finding nevertheless considerably raises question about the perceptual invariance of musical pieces under timbre change. In addition, Experiment 3 also reveals a new asymmetry: for both groups of participants, changing the

timbre from piano to orchestra was more detrimental than the reverse order compared with the same-timbre conditions. In the present case, it is difficult to determine the relative contributions of change in instrumentation, in interpretation or in other characteristics associated with the different performances.

Although the change in instrumentation was not instantiated in exactly the same way in Experiments 1 and 3, it was of interest to run a meta-analysis of both studies to highlight the stable outcome emerging from the whole set of data. A further Musical Expertise (2) × Timbre Change (2) × Instrumentation (2) × Style (2) between-subjects ANOVA was conducted to investigate the additional factor of style (Reynolds versus Liszt). There was a main effect of Musical Expertise with higher recognition scores for musicians than for nonmusicians, $F(1,133) = 17.58$, $p < .0001$, $MSE = 123.80$. There was a significant main effect of Style with higher recognition scores for Liszt than for Reynolds, $F(1,133) = 38.03$, $p < .0001$, $MSE = 123.80$. There was a main effect of Timbre Change with higher recognition scores for same-timbre than for different-timbre conditions, $F(1,133) = 64.64$, $p < .0001$, $MSE = 123.80$. This timbre effect was modulated by the musical style, $F(1,133) = 4.90$, $p = .028$, $MSE = 123.80$: there was a greater advantage of same-timbre over different-timbre conditions for Liszt than for Reynolds. Interestingly, this interaction was mostly generated by the fact that the recognition of Liszt benefited more from the absence of timbre change than did that for Reynolds, and this is true for both musicians and nonmusicians. There was also a significant three-way Musical Expertise × Timbre Change × Style interaction, $F(1,133) = 3.98$, $p = .048$, $MSE = 123.80$ (Fig. 4). This interaction is merely due to the absence of difference between same- and different-timbre conditions for the nonmusicians in the contemporary music excerpts. Finally, a significant three-way Timbre Change × Instrumentation × Style interaction, $F(1,133) = 8.00$, $p = .005$, $MSE = 123.80$ (Fig. 5), underlines the fact that going from piano to orchestra was more detrimental than going from orchestra to piano for the Liszt, whereas the reverse (although nonsignificant) tendency was found for the Reynolds materials. Once again, this interaction may be due to a combination of change in instrumentation and performance factors.

To summarize, timbre is encoded in the memory trace for complex musical materials and affects the subsequent recognition of both contemporary and tonal music in musicians and nonmusicians, except that the nonmusicians unfamiliar with the contemporary style do not seem to possess the schemata necessary to deeply encode the contemporary music (even without timbre change), which probably masks a possible influence of timbre.

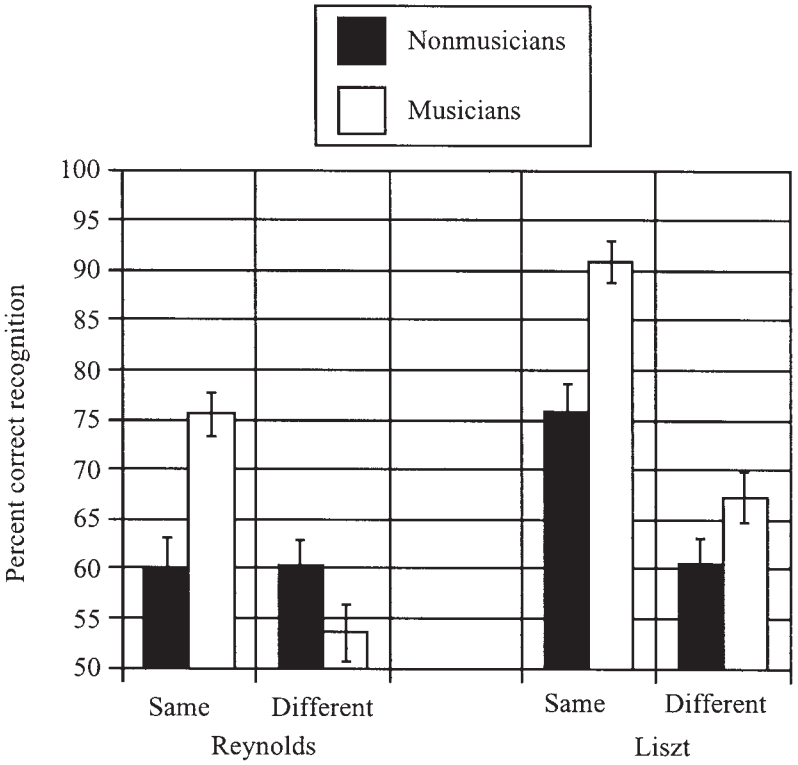

Fig. 4. Comparison of Experiments 1 and 3. Percent correct recognition as a function of musical expertise, musical style, and timbre change.

General Discussion

The present study investigated the recognition of musical pieces under instrumentation change. Although this issue has already been addressed with simplified musical stimuli, no studies have considered this issue with real performances of contemporary music composed by world-class composers. The first main outcome was to demonstrate that timbre influences the memorization and the subsequent recognition of real excerpts of contemporary and tonal music. This finding indicates that timbre qualities are part of the memory trace associated with musical materials. It also suggests that the processing of timbre, pitch, and rhythm in memory coding are not independent for real musical excerpts. This finding fits with previous results in the literature (Crowder, 1989; Melara & Marks, 1990a, 1990b, 1990c; Peretz et al., 1998; Pitt & Crowder, 1992; Radvansky & Potter, 2000). In particular, Radvansky et al. (1995) and Radvansky and Potter (2000) showed with real, moderately complex music that timbre is

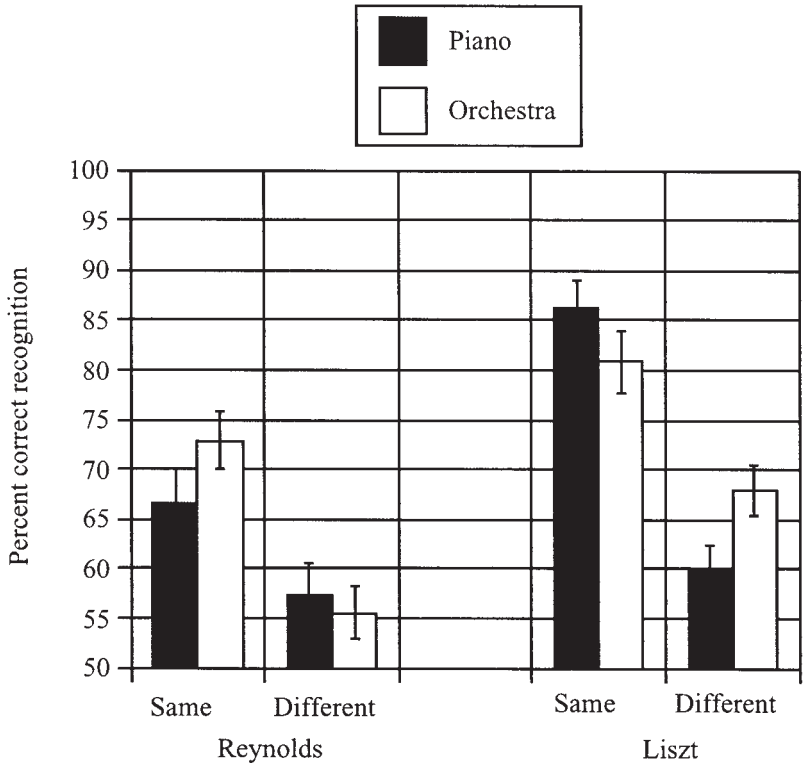

Fig. 5. Comparison of Experiments 1 and 3. Percent correct recognition as a function of instrumentation in the learning phase, musical style, and timbre change.

actually encoded in listeners' musical representations and influences the recognition of musical excerpts.

The second important result is that a change in timbre may be as detrimental for memory performance in musicians as it is in nonmusicians (at least for Western tonal pieces). This finding contradicts several empirical reports showing that nonmusicians were more sensitive to the influence of timbre change than were musicians (Beal, 1985; Pitt & Crowder, 1992; Wolpert, 1990). The present finding goes one step further by showing that the effect of musical expertise even tended to work contrary to what was reported in the literature with contemporary music. With this musical style, musicians were more influenced by the timbre change than were the nonmusicians; however, this could be due to the weak ability of the nonmusicians to encode and recognize contemporary music even without timbre change. Nevertheless, this finding may be counterintuitive at first glance, but it is easily understandable if we consider that timbre has a greater role as a form-bearing dimension in Reynolds's

music. In the present study, musicians were highly familiar with contemporary music and probably possessed some abstract schemata of this musical style. When listening to excerpts from *The Angel of Death*, they would probably accurately notice that timbre is an important form-bearing dimension for the composer. As a consequence, musicians accurately devoted attentional resources to this dimension. Experiment 2 adds evidence that this allocation of resources was not task-dependent and actually corresponded to a natural way to pay attention to the Reynolds excerpts. As a consequence, when a change in instrumentation occurred in the second phase of the experiment, recognition was highly difficult, if not impossible. It should be noted that this pattern of data was even observed in the musician group with a professor of ear training who had considerable expertise in contemporary music, suggesting that musicians' performance levels can hardly be considered as a failure in musical expertise in our participants.

By contrast, the perception of Reynolds's thematic materials by nonmusicians seems to differ considerably from that of musicians. This difference could be related to the fact that musically untrained participants were not at all familiar with this music. For almost all of them, this was even the first time they had listened to this style. That is to say, they were almost entirely attuned to Western tonal music heard in everyday life and mainly possessed the abstract schemata necessary to encode tonal, but not contemporary, music. For these participants, the great novelty evoked by Reynolds's materials, in contrast to tonal music, is based on the considerable discontinuity of rhythm, melodic contour, and loudness, as well as timbre. The effect of musical expertise found in Experiment 1 thus probably reflects the fact that the two groups, owing to their different musical backgrounds, were not sensitive to the same characteristics, because their abstract schemata differed or were nonexistent for the contemporary music among nonmusicians. Experiment 3 provided further evidence for this interpretation. When the piece is in a style more familiar to both groups of participants, they performed similarly, both being influenced by a change in timbre.

Finally, the last issue addressed by this study concerned the participants' abilities to memorize the Reynolds excerpts. Not surprisingly, the study confirmed that contemporary music is more difficult to memorize than tonal music. However, it should be emphasized that the participants performed rather well with the contemporary music. At first glance, the moderate performance of the participants may be considered as rather disappointing, especially for the nonmusicians. However, it is worth noting that most of the nonmusicians had never listened to contemporary music before and globally reported disliking this style of music. In this context, the fact that they succeeded in memorizing contemporary excerpts that

they were listening to for the first time and in recognizing them at average levels above chance is somewhat remarkable. This suggests that the memory system manages to abstract relevant structures of this style of music, even for listeners who are definitely unfamiliar with it. By contrast, musically trained participants familiar with contemporary music managed to encode more salient features, and their performance increased compared to that of nonmusicians, even when they had listened to the musical excerpts only once. This suggests that there are features in contemporary music that are immediately perceptible and memorizable by both groups of listeners when instrumentation does not change.

In addition, although performance was moderately above chance (averaging 60% and 76% in Experiment 1 for nonmusicians and musicians, respectively, in the same-timbre condition), this performance level should be evaluated in light of the difficulty of the task: nine excerpts of 20 s on average were to be memorized and then recognized when interleaved with nine other excerpts of the same duration. Since the foil excerpts were taken from the same piece, they shared a lot of similarities with the target excerpts, which rendered the task quite difficult. The fact that participants performed above chance in this experimental setting demonstrated that at least some of the sophisticated features of contemporary music could actually be perceived and stored in memory from a first hearing. This cognitive ability is obviously not dependent on musical training or familiarity with the style, because even nonmusicians performed above chance in Experiment 1 in the same-timbre condition. Of course, their performance was only moderately above chance. However, this performance level should be compared with the levels usually found in the field of implicit learning studies (Bigand, Perruchet, & Boyer, 1998; Dienes & Longuet-Higgins, 2004; Stadler & French, 1998; Tillmann & McAdams, 2004). In this domain of research, performance scores of 60% are considered to demonstrate the ability of the cognitive system to extract significant parts of a highly complex organization underlying artificial sequences of stimuli. When placed in this context, the present findings are encouraging for contemporary music: contrary to the most widespread opinion, they demonstrate that listeners capture several sophisticated features of this musical style from the first hearing, even when they are entirely unfamiliar with the style.[4]

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