Effects of Musical Context on the Recognition of Musical Motives During Listening

Cecilia Taher, Robert Hasegawa,
& Stephen McAdams
McGill University, Montreal, Canada

Previous research suggests that musical context affects the formation of similarity relations among motivic/thematic materials during listening, and that three contextual aspects, namely contrasts in surface features and the organization and development of the musical materials, shape the listening experience of complete works. We empirically investigate the effects of these three contextual aspects on the perceived similarity of motivic variations while listening to Boulez's *Anthèmes*. This piece exists in two versions: 1) solo violin, and 2) violin and electronics. They contain clear categories of motivic materials, whose recognition can be studied within the natural contexts of the two versions. In Experiment 1, participants freely classified motivic variations extracted from *Anthèmes 1* representing different motivic categories. In Experiment 2, participants provided dissimilarity ratings for these variations. From these results, motivic models were selected for each category. In Experiment 3, musicians identified variations of the models while listening to either version of *Anthèmes*. The results indicate that musical contexts that are more contrasting on the surface, or more predictable in terms of motivic features and organization, facilitate the identification of motivic variations, whereas the overall formal development of the musical materials and their context over time disturbs the recognition of those variations.

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Music unfolds in time, and therefore an important part of its artistic and expressive potential comes from its ability to play with different contextualizations of similar motivic/thematic materials. Accordingly, discovering the many shapes that motivic/thematic materials acquire throughout different musical settings is perhaps among the most engaging aspects of the listening experience of much Western music. Context is as essential to music listening as time itself, and, in this sense, a study of the perception of motivic materials that disregards the effects of the musical context is incomplete. Musicians commonly describe or define musical compositions in terms of the development and organization of musical elements over time (form), highlighting the point that the musical context is part of the very essence of a musical work. In line with this, empirical studies have suggested that the musical context shapes the perception of motivic/thematic materials and their relationships during music listening (Clarke & Krumhansl, 1990; Deliège, 1989, 1992; Deliège, Mélen, Stammers, & Cross, 1996; Lalitte et al., 2004; Margulis, 2012; Tillmann & Bigand, 1996). Particularly relevant to the present study, research has shown that familiarity with the original musical context of motivic fragments facilitates the identification of thematic relationships (specifically, the sense of belongingness to the same musical theme) among those fragments when heard in isolation from their context (Lalitte et al., 2004). Nevertheless, little is known about the specific contextual factors of the musical structure that influence the listeners' sensitivity to motivic/thematic similarity relations.

Considering previous findings that the perception of real musical works is different from that of artificial musical stimuli (Lamont & Dibben, 2001), and recognizing the importance of approaching the study of music perception through compositions taken from the standard repertoire, we believe that it is particularly valuable (perhaps even necessary) to investigate contextual factors as they are naturally manifested in music created for artistic (rather than research) purposes. This investigation seems to be indispensable for post-tonal music at least for two reasons. First and most broadly, many accounts of post-tonal music have described motivic relationships as central to its coherence (especially in the absence of tonal syntax). Second and most specifically, the most traditional theoretical and analytical methods of post-tonal music (such as pitch-class set theory) have tended to emphasize abstract, atemporal (non-contextual) similarity relations whose perceptual validity has been seriously questioned by experimental

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research in music psychology (e.g., Bruner, 1984; Gibson, 1986, 1988, 1993).

Boulez's *Anthèmes* provides an ideal opportunity to study the effects of specific contextual factors on the listeners' perception of motivic/thematic similarity. Boulez's writings and compositions from late in his career show an explicit increased awareness of issues of perceptual similarity and their implication for composition, theory, and analysis (Goldman, 2011). Furthermore, the two versions of *Anthèmes* present clear sets of motivic variations in describable and categorizable, as well as potentially meaningful, contextual situations. The specific characteristics of the structure of the compositions and the musical settings in which the motivic variations are introduced provide natural musical environments to explore whether certain clearly defined features of the musical context affect the listeners' formation of motivic similarity relationships during listening. With the purpose of contributing to the understanding of the effects of contextual factors on motivic/thematic similarity perception, we present an empirical investigation of the contextual factors indirectly suggested by previous studies that are likely to affect the recognition of motivic variations while listening to Boulez's *Anthèmes 1* (for solo violin) and *Anthèmes 2* (for violin and electronics). Even when previous related studies have not sought to investigate the specific effects of context on the perception of motivic similarity, a synthesis of their findings supports the idea that contextual factors affect the perception of motivic/thematic similarity relationships during listening from two perspectives: how the perception of similarity relationships among musical motives is affected by the features of those motives (Clarke & Krumhansl, 1990; Deliège, 1989, 1992; Lalitte et al., 2004; Margulis, 2012), on the one hand, and how broad contextual aspects of music affect the overall listening experience (Clarke & Krumhansl, 1990; Deliège, 1989; Deliège et al., 1996; Lalitte et al., 2004; Tillmann & Bigand, 1996), on the other hand.

The Perception of Musical Materials and Aspects of the Musical Context

To our knowledge, the previous literature on the perception of similarity relationships among motivic materials and aspects of the musical context during real-time listening to entire compositions or movements has not investigated the specific contextual factors affecting the perception of motivic similarity relationships. Instead, studies have focused on examining either: 1) the effects of intrinsic features (i.e., musical characteristics inherent to the motives rather than aspects of the surrounding context) of clearly defined motivic/thematic materials on the perception of the similarity or recognition of those materials during listening (Clarke & Krumhansl, 1990; Deliège, 1989, 1992; Lalitte et al., 2004; Margulis, 2012), or 2) the effects of general structural characteristics of the compositions as wholes (broad aspects of the musical context) on general perceptual aspects of music rather than those specific to similarity (Clarke & Krumhansl, 1990; Deliège, 1989; Deliège et al., 1996; Lalitte et al., 2004; Tillmann & Bigand, 1996).

With respect to the first point related to the effects of intrinsic motivic features on similarity perception, only a few studies have directly and specifically addressed the recognition of motivic/thematic materials while listening to musical works or movements from beginning to end without pause. Deliège (1992) found that certain motivic materials (specifically, *Leitmotifs*) were easier to recognize during listening to the second scene of Wagner's *Das Rheingold* than were other materials. This result suggests that the intrinsic features play an important role in the perception of similarity relationships among those materials. Margulis (2012) found that the duration of repeating motivic/thematic materials affects the way in which listeners' perception of the relationships among them develops over the course of a composition. Specifically, her results indicated that musical repetition disturbs listeners' recognition of short repetitive motives and at the same time facilitates the identification of long repetitive themes. In other words, whether the length of a musical material affects its recognition is dependent on the temporal setting and repetitiveness of the material (contextual factors). Other experiments have suggested that the characteristics of the musical materials, particularly in terms of surface features (i.e., those intrinsic features that are perceptually most obvious, especially articulation, dynamics, and rhythm), influence listeners' ability to recognize the location of those materials within their musical context (Clarke & Krumhansl, 1990; Deliège, 1989; Lalitte et al., 2004). Even though these experiments do not deal with recognition of musical materials during real-time listening to musical compositions, they contribute to the understanding of the real-time listening experience in the sense that they assume that the participants localize the excerpts based on their previous hearing of the composition from beginning to end. Several factors suggest an effect of context: slight differences in the results of these experiments in terms of the features of the materials that were found to be relevant, the participants' ability to localize the materials, and differences in the repertoire used. This idea is supported by Clarke and

Krumhansl's (1990) finding that the specific location of a musical motive within the formal structure (whether it is located at the beginning, middle, or end of a formal section) can affect the listeners' recognition of that motive. Finally, the studies reviewed here deal most directly with the intrinsic characteristics of motivic/thematic materials that affect the perception of similarity relations among those materials when heard within their original contextual settings.

In reference to the second point concerning broad contextual effects on general aspects of music perception, first note that previous studies have defined the features of the musical context affecting the perception of the music only a posteriori on the basis of empirical observations (this is to say that contextual factors have previously been discovered through empirical observations rather than tested by means of them). Empirical research has demonstrated that contrasts in surface features are particularly relevant for parsing musical structures during listening (Clarke and Krumhansl, 1990; Deliège, 1989; Lalitte et al., 2004) and that the order of musical units of various lengths (from indivisible motives to large-scale divisible sections) is relevant for the listening experience (Lalitte et al., 2004; McAdams, Vines, Vieillard, Smith, & Reynolds, 2004; Tillmann & Bigand, 1996). In terms of the parsing of musical forms, segmentation patterns have been shown to be similar for musicians and nonmusicians, particularly for post-tonal music (e.g., Clarke & Krumhansl, 1990; Deliège, 1989; Deliège et al., 1996; Lalitte et al., 2004). The surface features that have been found to be relevant for real-time segmentation tasks include musical silences and contrasts in dynamics, timbre, texture, and tessitura (e.g., Clarke & Krumhansl, 1990; Deliège, 1989; Lalitte et al., 2004). In the context of her theory of cue abstraction, Deliège (2001) directly links the listeners' segmentation of the musical structure with their perception of musical similarity based on the results from a series of experiments. According to her theory, listeners parse the musical structure based on memory markers created by perceptually prominent features of the musical surface (cues). Because listeners naturally group similar musical events together, their segmentation of a musical composition reflects implicit mechanisms involved in the perception of similarity relationships among musical events. Accordingly, the perception of similarity relations is closely linked to musical segmentation. This idea has been empirically supported by perceptual studies demonstrating that surface contrasts marking internal (local) subdivisions of the formal sections of a post-tonal piece affect the listeners' perception of music similarity during listening (McAdams et al., 2004).

With respect to the perception of the order of musical materials, experimental studies have suggested that both musician and nonmusician listeners can perceive a sense of overall coherence (Tillmann & Bigand, 1996), and that musicians can identify the location of fragments in the formal structure (Clarke & Krumhansl, 1990; Deliège, 1989) and, they can even intuit the temporal function of motivic materials (Lalitte et al., 2004), although with difficulty, particularly when listening to post-tonal music. Furthermore, McAdams et al. (2004) showed that the large-scale formal organization (especially the order of large-scale formal sections) affects the listeners' perception of music similarity during listening of post-tonal music. The literature associated with the order of musical materials indicates that the organization and development of the musical units of diverse hierarchical levels—organization of local musical materials and overall development of the large-scale form—are relevant aspects of music perception.

Finally, contrasts in surface features and the temporal organization and development of musical materials are three aspects of the musical context, in the sense that their very definition depends on the musical surroundings. For instance, musical silences are effective segmentation cues only when there are cohesive periods of musical sounds before and after them (e.g., brief rests do not normally lead to the isolation/segmentation of single short tones intertwined with those rests). Similarly, the temporal position of a fragment within a composition is commonly defined in terms of the distribution of the remaining fragments (in effect, the term "organization" seems to be strictly linked to the notion of multiplicity of events), and the idea of development is necessarily associated with issues of time and organization. Following this, we argue that these three contextual cues are particularly relevant when listening to entire compositions.

Based on these previous findings concerning the recognition of motivic/thematic materials and perceptual aspects of the musical structure (setting) that affect the listening experience of artistic compositions, as well as the noted lack of research directly concerned with the specific musical context that affects the perception of similarity relationships among motivic/thematic materials, this paper explores the effects of contrasting moments in terms of surface features and the organization and development of the musical materials on the listeners' identification of motivic variations while listening to the two versions of Boulez's *Anthèmes*. First, a motivic and formal analysis of the two compositions is introduced. This analysis demonstrates how the characteristics of the musical surface and the organization and features of the motivic materials in the two compositions can serve to study their effects on motivic recognition. In addition, the analysis serves to select the motivic materials used as stimuli for the experimental portion of this paper. This selection was necessary because experimental situations investigating the perception of the totality of the motivic materials of the two versions of *Anthèmes* would have been impractical and would have compromised the validity of the results due to limited capacities of human memory and attention. Accordingly, the experiments presented in this paper are based on a reduced set of motivic materials from *Anthèmes.* Two preparatory experiments (Experiments 1 and 2) were exclusively designed to select the versions of the motivic materials in the composition that can function best as models or reference points for all the motivic variations appearing in the piece. These motivic models are necessary to investigate the effects of surface contrasts and musical organization and development on the recognition of motivic variations in Experiment 3. In this last experiment, participants hear a motivic model several times and subsequently search for variations of that model while listening to one of the two versions of *Anthèmes.*

Theoretical Analysis: Motivic Structure, Formal Segmentation, and Organization of Materials in Boulez's *Anthèmes*

Boulez describes the musical materials of *Anthèmes* as "recognizable musical objects" that are constantly transformed throughout the work (quoted in Goldman, 2001, p. 106). The composition is in this sense a paradigm of motivic variations. Boulez explains that the easily identifiable materials of *Anthèmes* are organized in ways that are often difficult to predict for the listener. Accordingly, a score-based theoretical analysis of the organization of the materials in the piece presented below suggests that some fragments are clearly more predictable than others. The motivic materials are framed at the large scale by one peculiar motive that consists of long tone(s) played in harmonics on the violin. This framing motive contrasts greatly in terms of surface features with respect to the rest of the elements of the work. Boulez calls the different versions of this motivic material "signals," alluding to their perceptual prominence. These signals are meant to orient the listening experience. Following this, issues associated with the identification of motivic materials, their organization, and contrasts in surface features are present at the conceptual and compositional level of *Anthèmes.*

Boulez's *Anthèmes* exists in two versions, *Anthèmes 1* (1992) for solo violin and *Anthèmes 2* (1997) for violin

TABLE 1. *Motivic and Formal Structure of Anthèmes (Both Versions)*

	Formal Sections								
Motivic Categories	I	II	III	IV	V	VI	VII	VIII	IX
Long tone	✓	✓	✓	✓	✓	✓			✓
Melodic	✓				✓		✓	✓	✓
Trill	✓	✓		✓	✓	✓	✓		✓
Scale	✓	✓		✓	✓	✓	✓	✓	✓
Pizzicato			✓					✓	
Battimento	✓								✓
Grace note		✓				✓			
Tremolo				✓					
Staccatissimo				✓		✓			
Broken arpeggio							✓		✓
Plucked trichord								✓	

Note: Column 1 shows the motivic categories or families. Columns 2 to 10 show the presence of motivic categories in the nine large-scale sections of the piece.

and electronics. The second version is strictly derived from the original one, in the sense that it is based on the same motivic materials and an equivalent large-scale formal structure (general temporal organization of the motivic materials). Furthermore, the procedures defining each formal section, such as patterns of organization of the materials and musical factors causing internal groupings, are remarkably similar. The correspondence between the two versions of the work is such that every musical note of *Anthèmes 1* can be tracked in *Anthèmes 2.* Even so, the two versions are considerably distinct and independent. Most obviously, in *Anthèmes 2*, the formal structure is greatly enlarged (the performance time for the second version is approximately twice as long as that for the original work), and the electronics create important timbral transformations. Consequently, the two versions of *Anthèmes* can be seen as two different musical settings of the same set of motivic variations and formal procedures.

Table 1 shows the motivic and large-scale formal structure of *Anthèmes*, which is exactly the same for the two versions of the work. Column 1 shows the motivic categories or families. These were analytically determined based on articulation style, bowing technique, character (in many cases transparently reflected by the expression markings in the score), speed (as defined by the tempo indications and rhythmic notation), dynamic/intensity, texture, rhythmic pattern, and overall melodic profile. The motivic families are contrasted in terms of these aspects. The label of a motivic family refers to what appeared to be the most prominent common feature among all the motives of that family: Trill, Scale, Pizzicato and Long Tone (with the latter also using harmonics produced on the violin). Additionally,

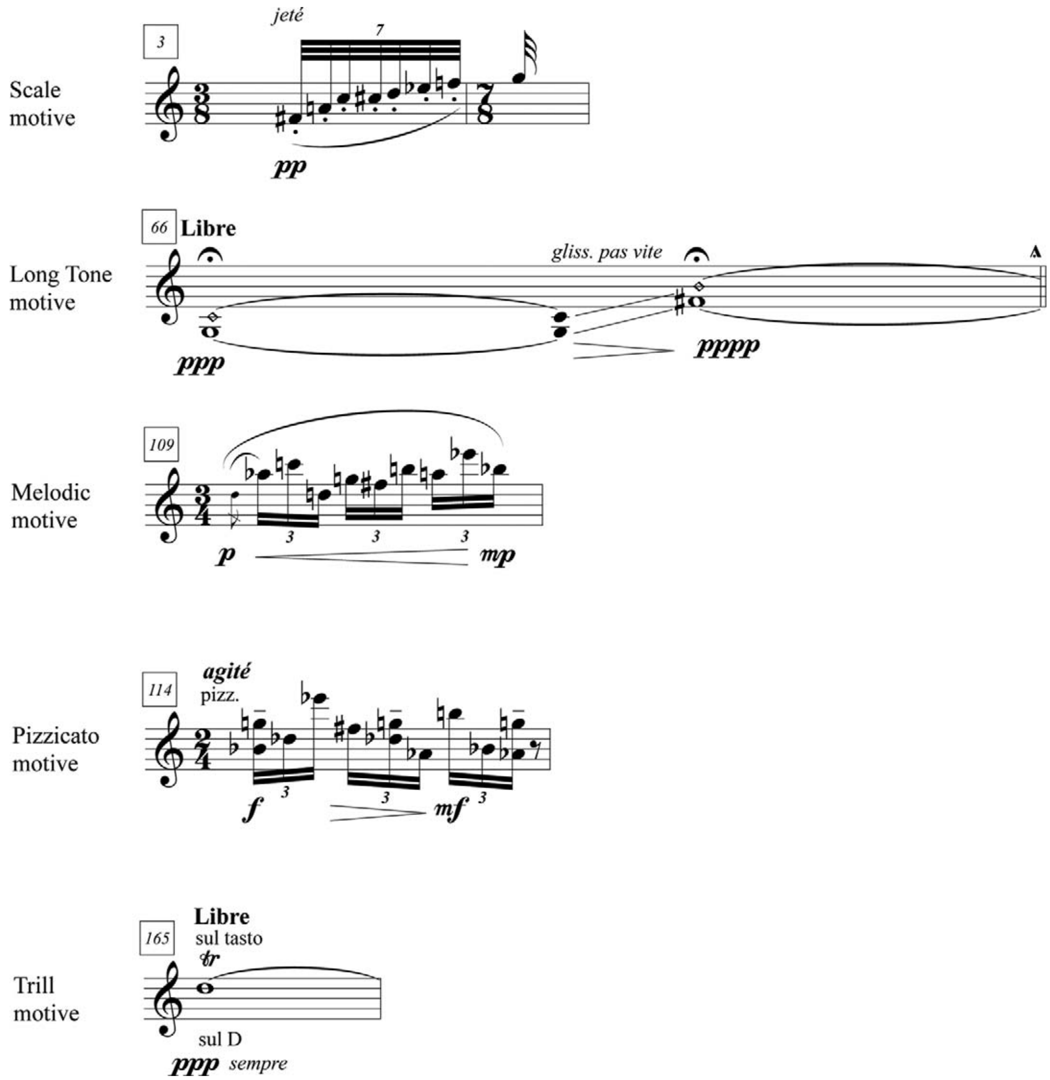

FIGURE 1. Examples of motives representing the five motivic families. The examples correspond to the motivic models used in Experiment 3.

the Melodic motives carry the least meaningful label because they are characterized by a relatively large set of features. They portray a singable style, slurred articulation, an isochronous rhythmic profile, and a relatively clear yet multidirectional pitch pattern. Furthermore, none of these characteristics is exclusive to the Melodic motives and, in this sense, the family lacks the unique characterization in terms of surface features that is typical of the other motivic families. The five families just described are illustrated in Figure 1 and are particularly relevant for this paper. Columns 2 to 10 of Table 1 show the nine large-scale sections of the piece. These sections were delimited following Boulez's own descriptions of *Anthèmes* in connection with the motivic materials featuring long tones (introduced above) and clear formal processes related to motivic organization that define each section (discussed below). This division into nine sections is further supported with the numbering of sections on the published score of *Anthèmes 2* and previous analytical studies of *Anthèmes* (Goldman, 2001, 2011). The check marks show the motivic materials appearing in each section. A complete analysis of the compositions as well as a description of all the motivic families can be consulted in Tables S1 and S2 of the Supplementary Materials accompanying the online version of this paper.

As shown in Table 1, the Trill, Scale, Pizzicato, Melodic, and Long Tone families are particularly representative of the form of the composition, since they appear in relatively larger numbers of formal sections and/or are

TABLE 2. *Formal Processes of Motivic Organization of Anthèmes (Both Versions), Per Section*

Large-scale form (measure numbers in *Anthèmes 1*)	**Formal Procedures**
Section I (mm. 1-2)	Introductory function. Presentation of one motivic instance of some of the most important motivic families
Section II (mm. 3-14)	Five consecutive statements of exactly the same motivic succession: Scale, Trill, Grace Note.
Section III (mm. 15-45)	Successive statements of motives from the Pizzicato family.
Section IV (mm. 46-66)	Two consecutive statements of the same motivic succession: Tremolo, Scale, Trill, Staccatissimo.
Section V (mm. 67-89)	Motivic families highly transformed. New motivic features incorporated into each family: Trills appear in multiple-stops (rather than monodically), Scales are slurred and relatively long (rather than *jeté/ricochet* and short), Melodic motives are rhythmically very complex and relatively long (rather than rhythmically isochronous and short).
Section VI (mm. 90-97)	Symmetrical (palindromic) distribution of the motivic categories: Scale, Trill, Grace Note, Staccatissimo, Grace Note, Trill, Scale.
Section VII (mm. 98-112)	Alternation of motives from the Melodic and Trill groups. The alternation pattern is unpredictably segmented by the occasional appearance of the Broken Arpeggio motive followed by musical silence.
Section VIII (mm. 113-143)	Random sequence of motives from the following categories: Melodic, Pizzicato, Scale, Plucked Trichord.
Section IX (mm. 144-165)	Lack of internal surface contrasts and clear segmentation points. The boundaries in terms of both musical features and formal segmentation between motives from Scale, Melodic, and Trill groups are blurred.

essential for the motivic definition of a section (i.e., they constitute the main or only motivic material of a given section). Following this, it was necessary to include the Pizzicato family, because these motives are the only materials of the third section of the work in addition to the Long Tone motive that marks the boundary of most sections. Based on this, the stimuli used in all the experiments presented below belong to the Trill, Scale, Pizzicato, Melodic, and Long Tone families.

Table 2 shows the formal processes related to the internal motivic organization of each of the nine sections of the piece. The formal sections are shown in the leftmost column. Measure numbers indicate the boundaries of the sections in *Anthèmes 1* (Boulez, 1992). In *Anthèmes 2*, the nine sections are delimited with numbers on the score (Boulez, 1997). The formal process that characterizes section IX can be described as an uninterrupted transformation of musical materials that results from the lack of clear formal segmentation and the interchange of features across motivic families (the motivic families are still clearly defined, but they share a relatively large number of features). Motives from the Melodic, Scale, and Trill families are stated almost without surface breaks. The lack of surface contrast results from the use of an isochronous rhythm, constantly slurred or long articulation style, and gradual dynamic (intensity) and pitch (register) transitions between the instances from different motivic categories. Indeed, section IX is the formal unit with the fewest internal surface contrasts in the piece. Conversely, section I, which has a clear introductory function, successively presents motivic materials from families of contrasting qualities separated by musical silence, and is relatively easy to segment internally. This section introduces the motivic materials only once, being thus unpredictable in terms of organization. Section II is the most predictable formal unit of the piece, stating the same ordered sequence of motivic materials (Trill-Scale-Grace Note) five times. Section IV is also based on a repeated fixed order of motivic materials. Because the sequence of motives is stated only twice, the section is not as predictable as section II. Section III is composed exclusively of Pizzicato motives. Section V presents the motives in their highest degree of transformation with respect to the majority of the motivic instantiations in the piece. In this sense, the section presents new musical features without introducing new motivic materials. The motivic materials become more difficult to predict in the sense that they share a smaller number of common features with the previous materials. The section is also unpredictable in terms of the succession of materials. Section VI is the second-shortest section (after the introductory section) of the work, and portrays a palindromic arrangement of four motivic materials (Scale-Trill-Grace Note-Staccatissimo-Grace Note-Trill-Scale). Section VII alternates motives from the Melodic and Trill families. The alternation is unpredictably interrupted with the Staccatissimo motive followed by musical silence, creating surface contrasts that suggest internal divisions of the section. Like section I, section VIII is very difficult to predict in terms of the order of presentation of motives, but is also easy to segment internally in terms of contrasts in surface features. In this second-to-last section of the piece, materials from contrasting families are presented in an apparently random order and are always separated by silence. Finally, sections II, V, and IX are particularly relevant for this study, because they are associated with contexts that can be clearly defined in terms of either internal segmentability or predictability. This is not the case for the remaining sections, where the context is determined by both segmentability and predictability (they do not provide contextual situations relatively free of confounding factors).

In *Anthèmes 2*, the nine sections are further differentiated from each other in terms of processes associated with the application of the electronic effects. During the majority of the sections, each motivic family features a different electronic effect. For each family, this effect might be the same or different across formal sections. Nevertheless, for each section internally, there is a strong link between electronic effects and motivic families. Sections V and IX are exceptions in this respect, because the same electronic effects are applied across most of the motivic families and constant reverberation resonates throughout the entire sections. As a result, the motivic materials fuse greatly. For this reason, these two sections might be particularly difficult to segment internally. Accordingly, the timbral qualities of these two sections with respect to the remaining sections are particularly relevant for the effects of surface contrasts investigated in this paper.

The analysis above intends to convey that *Anthèmes* is based on motivic variations framed in perceptually clear large-scale sections that can be systematically defined in terms of internal segmentability (surface contrasts) and the organization of the motivic materials (order of presentation of the materials) and their features (introduction of motivic features or degree of transformation of materials over time). Accordingly, the piece provides a natural musical environment to empirically investigate whether and how the perception of motivic similarity relations is affected by the three potentially meaningful contextual factors proposed in the introduction of this paper: 1) surface contrasts, 2) organization the materials and their features, and 3) overall formal development of the music (large-scale formal organization). The similarity of the two versions of *Anthèmes* in terms of the motivic materials and these three contextual factors, along with the difference between the two versions in terms of the individual musical events, the temporal dimensions, and the timbral characteristics, allow us to test the effects of the three contextual factors mentioned above on the perception of motivic variations in two experimentally equivalent, yet musically different, situations.

Experimental Hypotheses: From Theoretical Analysis to Empirical Research

We hypothesize that motivic materials set in contexts associated with contrasts in surface features or orders of musical materials that can be relatively easy to predict (such as reiterating ordered sequences of motives or commonly recurrent motivic features) would be easier to instantly recognize during real-time listening than materials set in difficult-to-segment and unpredictable musical contexts. Presumably, contrasting contexts would immediately work as attention capturers for listeners, improving their ability to detect motivic materials. Similarly, predictable musical contexts would supposedly cause listeners to intuitively anticipate motivic materials (including their features), facilitating the identification of those materials, especially when explicitly searching for them during listening. It is important to note that the hypothesis proposed here, that a predictable musical context facilitates the identification of motivic variations, is not incompatible with Margulis's (2012) findings that repetition of short motivic materials disturbs the listeners' ability to recognize those materials. First, our study deals with a specific type of repetition (i.e., varied repetition). Whereas it seems intuitively evident that exact or nearly exact repetition could easily become boring for listeners (leading their attention to nonrepetitive musical materials, as has been demonstrated by Taher, Rusch, & McAdams, 2016), varied repetition seems likely to attract the listeners' attention with interesting nuances of familiar yet always transforming materials. Second, the kind of predictability that we hypothesize would facilitate the recognition of motivic materials is related to the organization of those materials in relation to other materials and to the degree of variation of their features throughout the piece, rather than to the repetitiveness of the motivic materials as wholes. Restatements of motivic materials can occur in unpredictable musical contexts. Indeed, Margulis (2012, 2014) does not link her results to issues of predictability, but rather to aspects of attention and interest. Third, the predictability of musical materials is more likely to function as an effective cue for motivic identification in post-tonal music, where exact musical repetition is often purposely avoided and the materials are framed in nontraditional (mostly unexpected) formal schemes, than in tonal works (like the repertoire in Margulis's study), where musical repetition is the norm and formal organization can sometimes be obvious to the point of becoming uninteresting. Fourth, as reflected by the motivic analysis of *Anthèmes* presented above, the type of predictability associated with the organization of repeating motivic materials concerned with this paper refers to the internal organization of formal sections only (i.e., small-scale formal structure). Indeed, the large-scale form of *Anthèmes* does not follow an obvious (predictable) pattern. This leads to our third hypothesis, which consists of an overall decrease in motivic recognition over the course of the compositions. This hypothesis is supported by two points: 1) the unpredictable large-scale structure of *Anthèmes*, which, according to the hypothesis that predictable musical contexts should facilitate motivic recognition during listening of post-tonal music, would disturb motivic recognition in post-tonal compositions; and 2) the short duration of the motivic materials of *Anthèmes*, which, according to Margulis's findings, would lead to a decrease in recognition as the music develops over time.

A study of recognition of variations of musical materials during real-time listening requires the selection of musical materials that can work as models of those variations. In other words, it is not possible to identify variations without first hearing a model. Experiments 1 and 2 serve the preparatory purpose of determining which motives can best function as referential materials for listeners as they identify motivic variations while listening to *Anthèmes 1* or *Anthèmes 2* in Experiment 3. Experiment 1 has the purpose of selecting a reduced set of motivic variations that can accurately represent all the motivic instantiations of the five motivic families chosen for this study without being impractical in terms of the number of stimuli. In this experiment, participants freely classified the motivic variations from the five motivic families chosen on the basis of the analysis above. A clustering analysis obtained from the participants' classifications allowed for the selection of a reduced set of motivic instantiations representing the range of variation of the materials in the piece. This reduced set was used in Experiment 2 to determine the motives that worked best as models for detecting variations during listening to *Anthèmes* in Experiment 3. In Experiment 2, participants rated the similarity of all possible pairs of motives within each of the five motivic families. For each of the five families, the motivic instantiation perceived as being more similar to all the instantiations in the same family was chosen as motivic model. Materials belonging to the same family of a chosen motive should feature different yet limited degrees of similarity with respect to that motive (i.e., the motivic materials belonging to the same motivic family can be described in terms of how different they are from one another). Therefore, the motives that can work well as references or models for a family should in principle be those that can be converted into all the members of the family through minimum transformation.

Experiment 1: Free Classification of Motivic Materials

The aim of Experiment 1 was to determine whether free classification of motivic materials corresponded to the score-based analysis categories and to derive a hierarchical tree structure to select a representative subset of materials for Experiment 2.

METHOD

Participants. Seventeen musicians (aged 22–38 years, $M = 29.3$ $SD = 5.5$, seven females) volunteered to participate and provided informed consent. Six of the participants (35%) were familiar with *Anthèmes.* All had completed the music theory and musicianship requirements for the Bachelor of Music at McGill University or equivalent. Four of the participants were doctoral students in music, had completed at least four years of academic training in post-tonal theory or analysis exclusively, identified themselves as composers or researchers of post-tonal music, and indicated contemporary art music as one of the types of music that they heard most frequently. An examination of the descriptive data suggested no differences between this group and the rest of the participants. Therefore, all data were analyzed together. Before the experiment, participants passed a pure-tone audiometric test using octave-spaced frequencies from 125 Hz to 8 kHz and were required to have thresholds below 20 dB HL (ISO 389–8, 2004; Martin & Champlin, 2000). This study was certified for ethical compliance by the McGill University Research Ethics Board.

Stimuli. The stimuli were 54 short motives extracted from *Anthèmes 1.* The motives did not constitute a comprehensive account of all the instances of motivic materials associated with one of the five families in the composition. Instead, they consisted of examples representing the range of variation of the categories. A complete list of motives appears in Tables S1 and S2 of the Supplementary Materials accompanying the online version of this paper. In general, the excluded motives were very similar to the included ones. For instance, five out of all the motivic members of the Scale family consisted of 8-note ascending scales built with similar interval collections and identical rhythm, and played with the same articulation and at nearly identical tempi. Keeping in mind that these five motives from the Scale family were nearly identical in all characteristics except for specific pitch content, we chose two motives with a pitch content that best represented the five scalar 8-note motives as a whole as well as the range of variation among them.

Two of the included motives were hybrids of the Trill and Melodic families, in the sense that they presented important features of both families. These motives were included in both Experiments 1 and 2 with the purpose of investigating perceptual aspects of motivic similarity and categorization (family belongingness) that are not directly related to this paper and are reported elsewhere (Taher, 2016). As discussed below, these hybrid motives appeared to form their own perceptual group. Accordingly, they were excluded from Experiment 3 and are not discussed in detail in this paper. The duration of the sound files ranged from 0.47 to 21.12 s ($M = 4.22$ s, $Median = 2.53$ s, $SD = 4.32$ s). All motives were short in theoretical terms, in the sense that they were practically indivisible units belonging to a very small level of the structure. This was the case even for the longest motives, whose relatively long duration was due to the use of very long, sustained tones.

The stimuli were amplified through a Grace Design m904 monitor (Grace Digital Audio, San Diego, CA) and presented over Dynaudio BM6a loudspeakers (Dynaudio International GmbH, Rosengarten, Germany) arranged at $\pm 60°$, facing the listener at a distance of 1.5 m. In order to extract the stimuli, the entire CD track (Boulez, 2013) of *Anthèmes 1* was imported to Audacity at a sampling rate of 44.1 kHz. The sound files were cut and exported as .WAV files with 16-bit amplitude resolution. Editing of the sound files was avoided to the extent possible. A minimum amount of fade-out was added when the motives were elided with succeeding musical material. The fade-out time depended on the motive. The maximum levels of the sounds across excerpts ranged from 45 dB to 70 dB SPL, as measured with a Bruel & Kjaer Type 2205 sound-level meter (Bruel & Kjær, Nærum, Denmark) positioned where the center of the listener's head would be. The recording used for extracting the stimuli was Jeanne-Marie Conquer's performance at IRCAM in 2002 (Boulez, 2013). This version was chosen due to the high quality of the performance in terms of articulation and phrasing, the experience of the performer in playing Boulez's music, and the clarity of the sound in general. In addition, prior to the completion of this recording, Jeanne-Marie Conquer had recorded the piece in the presence of Pierre Boulez.

Procedure. A free classification paradigm was used. The 54 motivic materials were represented by randomly numbered squares and presented to participants on a computer screen. Participants could listen to the materials by clicking on the square as many times as they wished and in any order. Once the participants had heard a motive at least once, they could freely move it around the computer screen by clicking and dragging. Following this procedure, participants freely sorted all 54 materials into as many categories as they wanted. Categories were represented by empty boxes (rectangles) on the computer screen. An empty category was always available. Participants were instructed that all motives were to be included in one and only one category, but it was possible to form single-motive groups. Participants were allowed to connect categories that they thought were related and were asked to provide labels for the categories they formed. For the purposes of this paper, connected categories were considered as part of one larger category (i.e., only categories of the largest hierarchical level were taken into account), and labels were ignored. All participants read the same instructions and were then asked to explain them to the experimenter. The experimental trials were preceded by a practice trial monitored and assisted by the experimenter to ensure that the participant understood the task.

Data analysis. The participants' classifications were converted into a 54×54 co-occurrence matrix in which each cell indicated the number of participants grouping two motivic materials into the same category. This matrix was converted into a dissimilarity matrix in which each cell showed the proportion of participants sorting the two corresponding motives into separate groups. A hierarchical clustering tree was derived from the dissimilarity matrix using the average linkage method. This method, which calculates distances between two items or clusters based on the mean distance of the objects within them in a hierarchical way, was chosen for giving the highest correlation between the dissimilarity matrix and the cophenetic matrix (distances between motives in the hierarchical tree): $r = .98$, $p < .0001$. In this representation, the lower two motives (or groups of motives) are joined in the tree, the larger the proportion of participants classifying them within the same category, and, presumably, the higher the perceived similarity of the motives.

RESULTS AND DISCUSSION

The averaged motivic categorization performed by the 17 musicians is represented in the clustering analysis

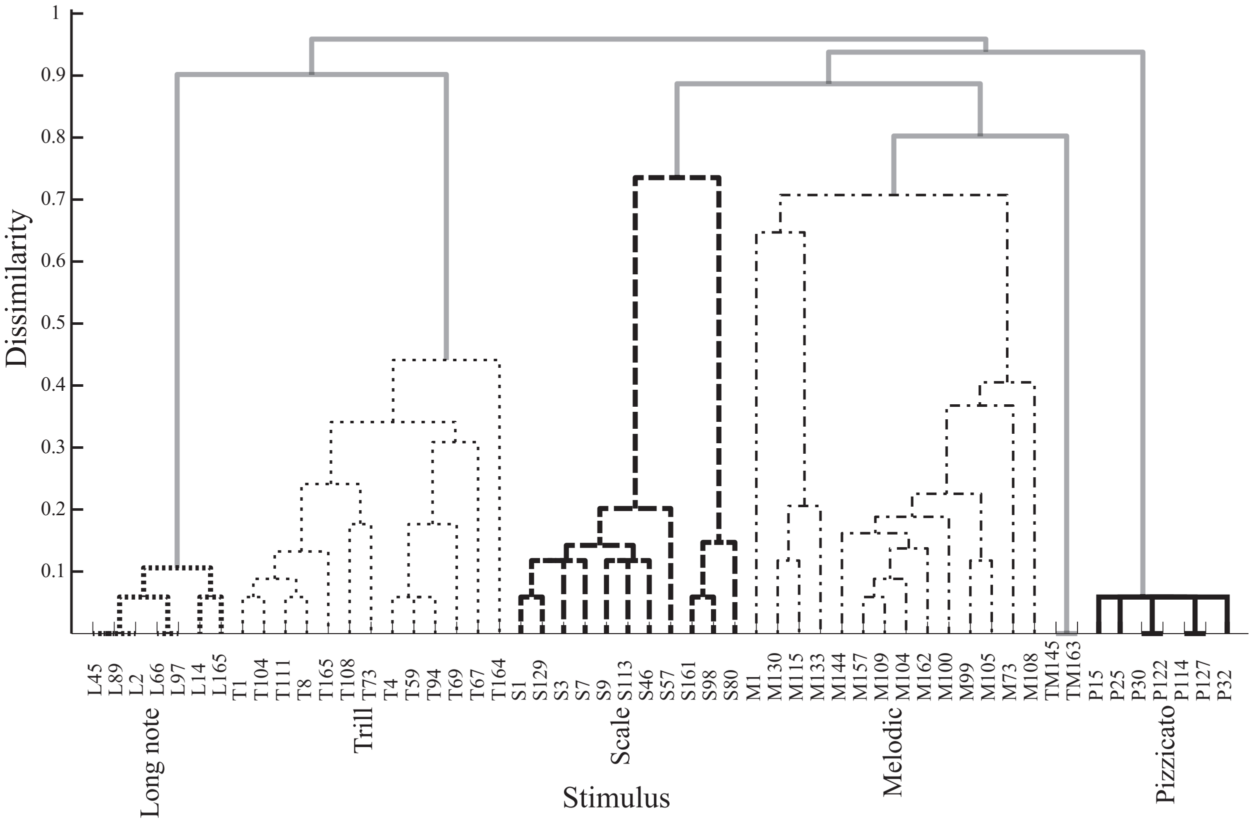

FIGURE 2. Hierarchical clustering dendrogram obtained from the free-classification of motivic materials extracted from *Anthèmes 1* in Experiment 1. The label of the motivic materials along the *x*-axis consists of the first letter of the name of the motivic family followed by the measure number that corresponds to the onset of the material.

shown in Figure 2. The label of the materials consists of the first letter of the name of the motivic family (L for Long Tone, T for Trill, S for Scale, P for Pizzicato, and M for Melodic) followed by the measure number that corresponds to the onset of the material. For instance, L2 means Long Tone motive starting on measure 2 (*Anthèmes 1*). The *y*-axis indicates dissimilarity values estimated by the clustering algorithm on the basis of the number of participants classifying a pair of motives as members of the same category (lower dissimilarity value) or different categories (higher dissimilarity value). The larger the number of listeners including two motives within the same group, the lower on the *y*-axis the branches corresponding to those two motives join. In addition, motives that are most frequently categorized as belonging to the same group appear closer together along the *x*-axis. Following this, the motives from the Long Tone family differ the most from the motives from the Pizzicato family (because they join only at the top of the tree structure). The five motivic families defined through analytical methods (Long Tone, Trill, Scale, Melodic, Pizzicato) are displayed in different line patterns in Figure 2.

In general, the clear structure of the clustering tree reflects the perceptual validity of the five motivic families analytically defined. Some of the motivic categories appear to be perceptually more coherent than others. This is reflected in the number and position of tree branches corresponding to each family. The two Melodic/Trill hybrid motives (TM) appear to belong more to the Melodic family than to the Trill family. Nevertheless, they only join the Melodic family near the top of the hierarchical tree, indicating that they are a relatively independent motivic family. Keeping in mind that differences in surface features were prioritized in the theoretical definition of the motivic families and recalling the ambiguous definition in terms of surface features of the Melodic and hybrid motives, these results confirm the importance of surface contrasts for the perception of motivic similarity reported in previous studies (Clarke & Krumhansl, 1990; Deliège, 1989; Deliège et al., 1996; Lalitte et al., 2004). The hierarchical

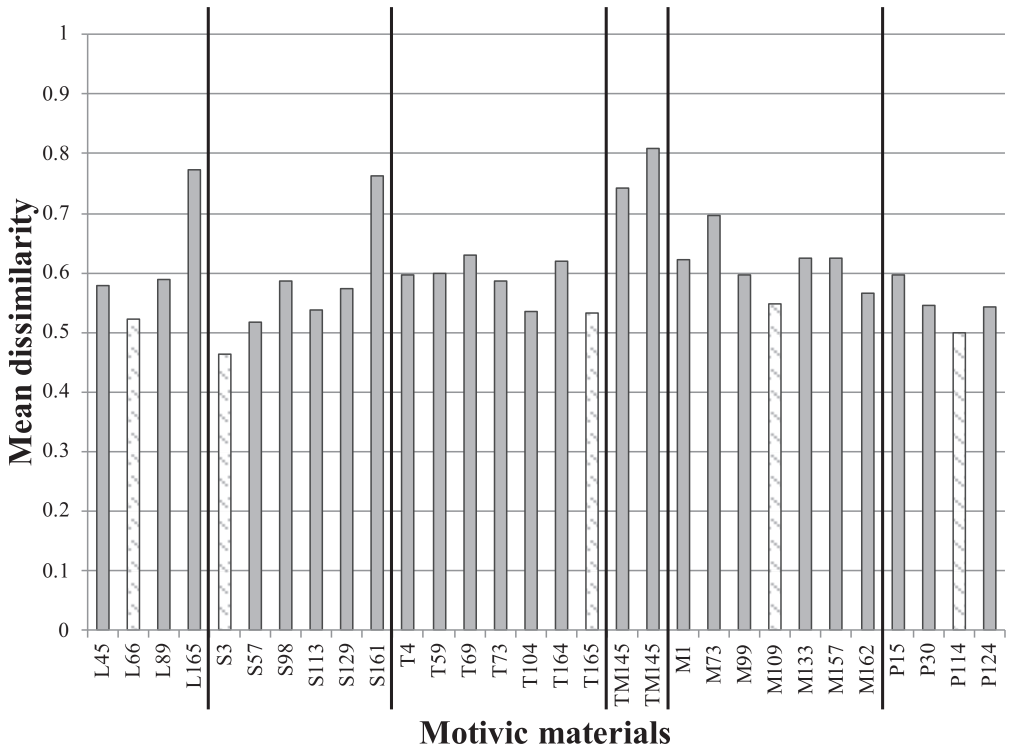

FIGURE 3. Mean dissimilarity ratings for motives in Experiment 2. The figure attempts to show how dissimilar/similar each motive is with respect to all the other motives within the same family. Zero dissimilarity corresponds to perfectly similar and 1 corresponds to very dissimilar. Different motivic families are separated with vertical lines. The motives with the lowest mean dissimilarities for each family are indicated with striped bars. L = Long Tone, S = Scale, T = Trill, M = Melodic, TM = Trill/Melodic hybrid, P = Pizzicatto.

analysis presented above served to select the motives used as stimuli in Experiment 2.

Experiment 2: Dissimilarity Ratings Within Motivic Families

The aim of Experiment 2 was to determine the similarity relations among motivic materials within each category in order to select models for each category to be used in Experiment 3.

METHOD

Participants. Twenty-three musicians (aged 19–36, $M = 23.2$ $SD = 4.9$, 12 females), all of whom had completed the music theory and musicianship requirements for the Bachelor of Music at McGill University or equivalent, were recruited through email, McGill Classifieds Online, and invitation in high-level music classes held at the Schulich School of Music of McGill University. Their hearing was verified with an audiometric test as in Experiment 1. Two (8.7%) of the participants reported being familiar with *Anthèmes*, although only one of them was able to identify the composer and title of the piece. All the participants were different from those in Experiment 1. Participants provided informed consent and were paid for their participation. One of the participants showed a threshold higher than 20 dB HL for the highest frequency. The participant was still admitted into the experiment based on his notable experience as a musician. Careful examination of the data revealed no important differences between the types of responses given by this musician and the remaining participants. Therefore, his data were included in the final analysis.

Stimuli. The stimuli consisted of 171 pairs of motives built with a selection of stimuli from Experiment 1 (see below). Their levels and presentation were identical to Experiment 1. From the 54 motives used in Experiment 1, 29 were selected to represent a large variety of levels from the clustering analysis (i.e., branches of various heights in Figure 2). We chose 50–57% of the members of each of the five families. (The selected motives can be seen along the *x*-axis in Figure 3.) This included one motive from the pair of motives consisting of a mixture of the Melodic and Trill families. Within each of the five main motivic families, the selected motives were paired in all possible ways, including both possible orders of presentation within each pair. The Melodic/Trill hybrid motive was paired with the motives selected from both the Melodic and Trill families. In addition, for quality control of the data, one identical pair consisting of two presentations of the same motive was included in each motivic family and was chosen randomly from the selected motives for each participant.

Procedure. All participants read the instructions and were then asked to explain them to the experimenter to verify their comprehension of the task. The experiment was divided into five blocks corresponding to the five motivic families. The order of the blocks was randomized. Each block consisted of two parts: 1) familiarization phase, 2) similarity ratings. During the familiarization phase, participants heard twice all the members of a family played in random order, and were instructed to form an idea of the range of variation among all the motives during this part. Once the familiarization phase had been completed, participants heard each of the pairs of motives from the same family, one at a time, and provided a similarity rating on a continuous scale that ranged from identical to very dissimilar. Specifically, participants were asked to use the slider to indicate how much the motive played second resembled the motive played first. This was done based on previous research indicating that the perception of similarity of motivic materials can be asymmetric (see Bartlett & Dowling, 1988). Participants were explicitly told to use the rating scale independently for each motivic family (i.e., to base their judgements only and purely on motives belonging to each given family, disregarding the motives of the other families). They were informed that the aim of the familiarization phase was to help them better grasp the meaning of the scale and its labels in terms of perception of the motivic differences specific to *Anthèmes*. The motives of a pair were represented by rectangles on the computer screen that lit up while the motives were playing. The rectangle corresponding to the motive played first appeared to the left of the computer screen, and the one corresponding to the motive played second was to the right. The motives were played automatically the first time. Participants then had the option to play each or both of the motives from the pair one more time. The experimental trials were preceded by a practice trial monitored by the experimenter. The stimuli used during the practice trial were absent from the experimental trials. During the practice trial, participants had the opportunity to clarify any doubts concerning the procedure.

Data analysis. The dissimilarity ratings given to all the motivic pairs involving a given motive were averaged for each motive within each motivic family. Given that the purpose of calculating these averages was simply to quantify the degree of dissimilarity of each motive within its family, no statistical tests were applied.

RESULTS AND DISCUSSION

The mean dissimilarity for each motive is illustrated in Figure 3. Mean dissimilarities are shown on the *y*-axis, with zero corresponding to identical and 1 corresponding to very dissimilar. Note that there are 30 rather than 29 motives, because the Melodic/Trill hybrid motive (TM145) was presented as a member of both the Trill and Melodic families. Different families are separated with vertical lines. The motives with the lowest mean dissimilarities for each family correspond to the striped bars. L66, S3, T165, M109, and P114 are most similar to all other motives in their family, and are, in that sense, representative of their family. With the exception of T165, the motives with the lowest mean dissimilarities are relatively easy to differentiate (in the figure) from the motives with the next-to-lowest dissimilarity mean in each family. The dissimilarity mean of T165 is similar to that of T104, presumably because both T165 and T104 consist of a single trilling note and are thus two equivalent versions of the same motive. The motives with the lowest mean dissimilarities within each of the five motivic families were presented to the participants in Experiment 3 as the model whose variations were to be identified during listening to *Anthèmes 1* and *2*. A score-based analysis of the motives with the lowest dissimilarity means in each family showed that they were noticeably simple (in terms of the number and variety of their internal elements) and short (in terms of their total duration), especially with respect to many of the other motivic materials in the family. This simplicity and short duration made these motives particularly appropriate to be used as motivic models in Experiment 3, where the memorization of the models was essential for the completion of the task.

Experiment 3: Online Recognition of Motivic Variations

Experiment 3 directly investigates the listeners' online identification of motivic variations while listening to *Anthèmes*. For each of the five motivic families, participants heard the motivic model selected in Experiment 2 several times and then listened to either *Anthèmes 1* or *Anthèmes 2* (depending on the experimental group) from beginning to end without any pause or interruption. They were asked to press a key every time they heard a motivic variation of that model. The listeners' recognition of the variations from the five motivic families is interpreted in light of the analytical observations concerning the internal segmentability and organization of the nine sections of *Anthèmes 1* and *2* presented above. Based on the literature review and the direct link between musical context and time presented in the introduction, Experiment 3 attempts to provide evidence that can help answer the following research questions concerning the effects of musical context on motivic similarity perception during real-time listening to complete artistic compositions: (1) does the segmentability of the context in terms of surface features (surface contrasts) affect the listeners' identification of motivic variations? (2) does the temporal organization (order of presentation) of the musical materials and motivic features within the composition affect the listeners' identification of motivic variations? and (3) does the overall formal development of the music over time affect the listeners' identification of motivic variations?

METHOD

Participants. Forty musicians (all of whom had completed the music theory and musicianship requirements for the Bachelor of Music at McGill University or equivalent) were recruited through email, McGill Classifieds Online, and invitation in high-level music classes held at the Schulich School of Music of McGill University. They provided informed consent and were paid for their participation. Twenty musicians were randomly assigned to each of two experimental conditions (*Anthèmes 1* and *Anthèmes 2*). They were 19-31 years of age ($M = 22.7$, $SD = 2.9$, 15 females) for *Anthèmes 1* and 20–44 years ($M = 26.3$ $SD = 6.3$, 9 females) for *Anthèmes 2*. They all passed an audiometric test. Only one participant (5%) reported being familiar with *Anthèmes 1*, although he/she was unable to identify the composer and title of the piece. Two participants (10%) reported familiarity with *Anthèmes 2* and could identify the composer and title of the piece. Three of the participants (7.5%) had participated in Experiment 1 and four others (10%) had participated in Experiment 2. Considering that Experiment 3 was run approximately 5–6 months after Experiments 1 and 2, and that the participants who were unfamiliar with *Anthèmes* in Experiments 1 and 2 were still reporting unfamiliarity with the piece in Experiment 3, we opted to disregard this minor overlap of participants.

Stimuli. The experimental stimuli consisted of one motive taken from *Anthèmes 1* serving as the model for each of the five motivic families, and the entire recording of *Anthèmes 1* by Jeanne-Marie Conquer at IRCAM in 2002 (Boulez, 2013) for one group or *Anthèmes 2* by Jeanne-Marie Conquer at IRCAM in 2008 (Boulez, 2009) for the other group. The motivic models corresponded to the motives with the lowest mean dissimilarity in each of the five families according to the results of Experiment 2. The five motivic models are shown in Figure 1. The model for the Long Tone family was shortened for practical purposes. The model faded out on the second note, after the glissando. For the practice trial, an artificial musical composition was created. This composition consisted of a musically arranged succession of the 29 motives used in Experiment 2.

All the stimuli were amplified through a Grace Design m904 monitor (Grace Digital Audio, San Diego, CA) and presented over Sennheiser HD280 Pro earphones (Sennheiser Electronic GmbH, Wedemark, Germany). Sounds were played at a level ranging from 65 dB to 75 dB SPL, as measured with a Bruel & Kjaer Type 2205 sound-level meter and a Bruel & Kjaer Type 4153 artificial ear to which the headphones were coupled (Bruel & Kjær, Nærum, Denmark). The models were presented in stereo, whereas the entire compositions were presented in mono (mixed channels). Listeners were seated in an IAC model 120act-3 double-walled audiometric booth (IAC Acoustics, Bronx, NY).

Procedure. The experiment had a between-subjects factor with two levels associated with the groups hearing *Anthèmes 1* or *Anthèmes 2*. Each condition was divided into five blocks corresponding to the different motivic families. The blocks were presented in random order.[1] Each of these blocks consisted of two phases: (1) familiarization with the model, and (2) online (real-time) identification of musical materials related to the model while listening to the pieces. Participants were encouraged to take notes about the motives during the familiarization phase and keep them as reference during the online identification task. During the

[1] For participants listening to *Anthèmes 1*, each of these five blocks was itself performed three times, using the same stimuli, so that participants completed the same tasks with the stimuli belonging to one motivic family three times in direct succession. This was done in order to investigate the effects of repeated exposure to the complete piece on the recognition of the motives from each family. Statistical tests (ANOVA and logistic regression) suggested that listening to *Anthèmes* several times did not affect the listeners' recognition of the motivic variations. We believe that this apparent lack of effect of repeated exposure on motivic recognition was largely due to a global effect of repeated exposure across the entire experiment, during which participants heard the piece a total of 15 times one after the other. Because the present paper does not deal with the effects of repeated exposure to the same piece of music, only the data corresponding to the first listening associated with each motivic family are reported and discussed here. For details concerning repeated exposure to *Anthèmes 1*, see Taher, 2016.

familiarization phase, participants heard the model of a motivic family eight times. After that, they listened to the piece corresponding to their group and pressed the space bar of the computer keyboard every time they heard something in the music that reminded them of the model. The term "model" was not used in the instructions (the instructions can be read in Table S3 of the Supplementary Materials).

A practice trial preceded the experimental blocks. The motive used for the familiarization phase of the practice trial was not used in the experiment and was the motive with the second-to-lowest dissimilarity mean according to the results of Experiment 2. This was done to avoid increasing the participants' overall acquaintance with one of the motives used as models during the actual experiment. For the online identification task, the artificial version of the piece described in the Stimuli section was used.

The experimental condition associated with *Anthèmes 1* was completed in two 90-min individual sessions held on consecutive days (only the data corresponding to the first third of each of these two sessions is discussed in this paper, because this condition was part of a larger experiment studying the effects of repeated exposure to the same piece). The condition associated with *Anthèmes 2* was completed in one 120-min individual session.

Data analysis. The data output consisted of the time (expressed in ms) at which the participants pressed the space bar. With the exception of the data collected from the trials associated with the Long Tone family, data points within 2 s of the onset of motives belonging to the motivic family of the model that were not consecutive to motives from the same family were considered "correct" identifications of a motivic transformation/variation of the model. This 2-s window was determined based on previous studies using similar methods (Margulis, 2012), as well as on observation of the distribution of all responses (histogram) with respect to the onset of motives according to the theoretical analysis. For the analyses reported in this paper, consecutive versions of motives belonging to the same family were disregarded on the following grounds: 1) consistent with Boulez's idea of basing the piece on recognizable musical objects, consecutive versions of motives are generally rare in *Anthèmes*; 2) the relative number of consecutive presentations of motives is considerably larger for the Pizzicato family than for the other families; (3) the onset (segmentation) of consecutive versions of motives is in some cases much clearer (in theoretical, analytical, and perceptual terms) than in others; and (4) the onset of consecutive versions of motives is often extremely blurred (difficult to determine) in *Anthèmes 2* due to the electronic effects. Following this, including nonconsecutive versions of motives would make the data set relatively unbalanced, adding confounding factors that are difficult to analyze.

TABLE 3. *Temporal Window Used for the Data Analysis of the Long Tone Motives in Experiment 3*

	L2	L14	L45	L66	L89	L97	L165
Anthèmes 1	6.9 s	5.1 s	5.7 s	5.3 s	3.8 s	3.9 s	3.7 s
Anthèmes 2	6.4 s	8.5 s	4.8 s	5 s	4.9 s	6.1 s	8.5 s

The onset of motives from all families was determined through a score-based analysis. The exact location (measure number on the score and timing on the audio tracks) of all motives can be consulted in the Supplementary Materials accompanying the online version of this paper (Tables S1 and S2). Because the motivic families were largely defined in terms of the contrasting musical features (particularly surface features) among them, the segmentation of the grouping structure was straightforward. The exact temporal position of all motivic instances was determined using Audacity. All motivic statements were tagged while listening to the imported CD tracks and following the scores with annotations corresponding to the theoretical analyses.

The window chosen for the Long Tone motives was customized for each motivic instance. Data points falling between the onset of a Long Tone motive and either the end of the first glissando (in motives that include glissandi) or the end of the first note (in motives that did not include a glissando) were counted as "correct" identifications of a Long Tone motive. The longest of these (final note of the piece) was shortened to be equal in duration to the second-longest Long Tone motive, because it was disproportionately long (25 s). The customization of the window for the data analysis of these motives (shown in Table 3) was based on four criteria: 1) the features defining the motives of the Long Tone family change much slower than those that define the rest of the motivic families; 2) the glissando is a characteristic of the motivic model presented to the participants at the beginning of the trial, and it is also a feature of many (4 out of 7) of the Long Tone motives throughout the piece; 3) either the glissando or the end of the first long tone constitutes the first clear change within the Long Tone motives.

There were two types of incorrect responses (motivic variations not identified by listeners): 1) responses falling outside the time windows mentioned above, and 2) absence of responses (participants not pressing the space bar) for a given motivic instance. Each correct response was coded as 1, and each incorrect response was coded as 0. The average provides the proportion recognition/identification for a given instance of a motive. For the purposes of this project, false alarms (identifications of motivic instances belonging to a motivic family different from the motivic model) were ignored. First, an examination of the distribution of the data points did not reveal important clustered regions outside the onsets of the target motives for each trial. Second, due to the short durations of the motives, it is in some cases impossible to distinguish between a false alarm and a delayed response beyond the correct-response window.

Three statistical analyses were conducted. The first analysis provides a general overview of the effects of the contexts of *Anthèmes 1* and *Anthèmes 2* on the listeners' identification of motivic variations. The correct responses corresponding to all motivic instances of each motivic family were summed per participant individually and divided by the number of motivic instances corresponding to that family. This led to a proportion of correct responses representing each participant's recognizability of each motivic family for each version of the piece separately. Pairwise comparisons tested for differences in motivic recognition for each motivic family between the two versions of *Anthèmes*, in order to investigate whether the different contextualizations (differences in terms of individual musical events, temporal dimensions of the formal organization, and general timbral characteristics) of the motives in the two compositions affected the net identification of any of the families. Additionally, pairwise comparisons tested for differences in motivic recognition among the five motivic families within each version of the piece, in order to examine the relative internal consistency or similarity among the motives of each family with respect to that of the other families and whether that relative consistency was affected by the different contexts provided by the two versions of *Anthèmes* or not. Due to normality issues associated with proportional data, we used nonparametric tests: Mann-Whitney Wilcoxon for between-piece comparisons and Wilcoxon Signed Rank for within-piece comparisons with Bonferroni-Holm adjustment for multiple comparisons. All reported p values are corrected (p_{corr}).

The remaining two analyses specifically aimed to elucidate the three research questions presented above. The second analysis studied the effects of segmentability of the musical context, as well as the order of presentation of the musical materials and motivic features, on the listeners' recognition of motivic variations (research questions 1 and 2). Based on the importance of these aspects for the formal structure of *Anthèmes*, the participants' identification of all variations of each motivic model was calculated for each of the nine formal sections. For each section, the correct responses corresponding to all motivic instances—regardless of family—for that section were summed per participant individually and divided by the total number of motivic instances corresponding to that section. This gave a proportion of correct responses representing each participant's recognizability of motivic variations for each section of the piece in each of its versions. Pairwise comparisons tested for differences in motivic recognition for all pairs of sections within each composition. This type of analysis allowed for the study of the effects of segmentability and organization of the materials within the two versions of *Anthèmes*. Segmentability and organization of the materials are aspects defining the formal structure of both versions of the piece. Because the degree with which these aspects are instantly perceived (or not) is likely to depend on the specific context within which they operate, it seemed essential to test for differences in motivic recognition among the sections of each version of the piece separately (rather than across versions). Given that the contexts provided by *Anthèmes 1* and *2* do not differ in terms of formal segmentability and organization, but rather in terms of multiple musical aspects that are very difficult to quantify (and not treated differently in systematic ways in the two versions of the piece), statistical comparisons of the formal sections in one version of *Anthèmes* with respect to the other version would be extremely difficult to interpret. Accordingly, contextual effects associated with the two different musical contexts provided by *Anthèmes 1* and *Anthèmes 2* were investigated through comparisons of the distribution of motivic recognition across sections in one version of the piece with respect to the other. More details justifying this type of analysis can be found in the Results and Discussion section below. As before, nonparametric tests were used.

Finally, the third statistical analysis had the purpose of elucidating the effects of the general evolution of the musical context on the listeners' recognition of motivic variations (research question 3). Based on previous findings that the repetition of short musical materials interferes with the listeners' ability to identify those materials as the music proceeds (Margulis, 2012) and an obvious decreasing linear trend in motivic recognition from the beginning to the end of both versions of *Anthèmes* observed in our results, a logistic regression of the proportion of motivic identification (for each participant) on the nine formal sections of the piece was performed for each version of *Anthèmes* separately. In addition,

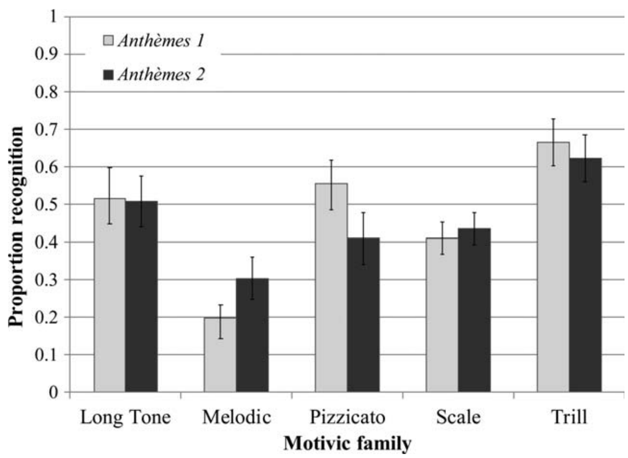

FIGURE 4. Motivic recognition per motivic family in the two versions of *Anthèmes* (Experiment 3). Error bars correspond to the standard error of the mean.

a multiple logistic regression analysis of proportion of motivic identification on Formal Section and Piece Version (specifically, the interaction term Formal Section × Piece Version) tested for differences between the regression trends obtained for each version of *Anthèmes.* Formal Section seemed a more appropriate factor for these logistic regression analyses than mere time in seconds, because this study is mainly concerned with musical context as directly linked to aspects of the overall formal development of the musical materials over time.

RESULTS AND DISCUSSION

The proportions of identifications of motivic variations for the five motivic families in each version of *Anthèmes* are illustrated in Figure 4. Across-piece pairwise comparisons of recognition of each motivic family (for each version of the piece in its entirety and independently of formal section) were not statistically significant, indicating that the motives of each family were recognized with similar accuracy in the two versions of *Anthèmes*: $z \leq 1.40$ $p \geq .16$. In principle, these results indicate that the overall differences in context (specifically, differences in terms of individual musical events, temporal dimensions of the formal organization, and general timbral characteristics) provided by the two versions of the piece affected the participants' recognition of each motivic family in similar ways. Nevertheless, differences in the distribution of the recognition of the families in the acoustic version compared to the electronic version of *Anthèmes* revealed that the similarity relations among the motives of each family relative to those of the other families were affected by the different contextual settings. We will now examine those in detail.

In *Anthèmes 1*, participants recognized a significantly smaller proportion of Melodic motives than Trill, Pizzicato, and Long Tone motives: $z \geq 2.97$, $p_{\text{corr}} \leq .02$, and a significantly smaller proportion of Scale than Trill motives: $z = 3.16$, $p_{\text{corr}} = .01$. The pairwise comparisons corresponding to *Anthèmes 2* gave a different distribution of significant differences among the motivic families, indicating that the similarity relations among the motives were perceived differently in the two versions of the piece. In the electronic piece, participants recognized a significantly smaller proportion of Melodic than Trill motives only: $z = 3.34$, $p_{\text{corr}} = .01$. All remaining pairs of motivic families were identified equally in statistical terms. Following this, the different contexts seem capable of affecting listeners' formation of motivic similarity relations in different ways. The Melodic family appears to be particularly difficult to identify in *Anthèmes 1* only. As illustrated in Figure 4, the motivic families with the highest and lowest recognition across both versions of the piece correspond to *Anthèmes 1* (suggesting a more even distribution of family recognition in *Anthèmes 2* than *Anthèmes 1*) and the motivic family with the lowest recognition among all families (across both versions of *Anthèmes*) corresponds to the Melodic family (of *Anthèmes 1*). The apparently enhanced recognition of the Melodic family during listening to *Anthèmes 2* with respect to *Anthèmes 1* can be explained by the further timbral differentiation among the motivic families added by the electronic effects. As described above, in *Anthèmes 2* different motivic families are commonly identified with different electronic effects, thereby enhancing their differences.

Most specific conclusions concerning the effects of context can be drawn from an analysis of motivic recognition per formal section of each of the two versions of *Anthèmes*. Statistical analyses of the listeners' recognition of motives in each of the nine sections of the work provide information that can elucidate the three research questions presented above. Figure 5 shows the proportion of motivic identification across all families for each of the nine formal units in both versions of the composition.

The first research question (effects of segmentability of the musical context) can be most directly addressed by comparing listeners' recognition of motivic variations in the final section of each version of *Anthèmes* to that of the remaining sections, because this section was analytically identified as the formal unit that was the most difficult to segment internally among all other units. For each version of the piece and among all sections of the piece, section IX was associated with the

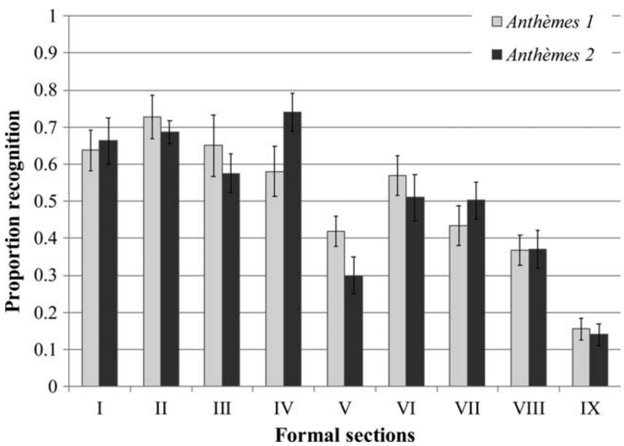

FIGURE 5. Motivic recognition per formal section in the two versions of *Anthèmes* Experiment 3). Error bars show represent the standard error of the mean.

largest number of statistically significant pairwise comparisons with the other sections of the proportion of motivic recognition, meaning that it was the section for which motivic recognition was lowest overall. As revealed by Wilcoxon Signed Rank tests, the proportion of motivic variations identified for section IX while listening to *Anthèmes 2* was significantly smaller than that for all the other sections: $z \geq 3.29$, $p_{corr} \leq .02$. Similarly, while listening to *Anthèmes 1,* listeners identified a significantly smaller number of variations for section IX than for all sections except VIII: $z \geq 3.14$, $p_{corr} \leq .04$. Motivic recognition was therefore particularly low during the final section of both versions of *Anthèmes*. In addition, a subtle difference in the results of the electronic composition with respect to its acoustic counterpart seems worthy of discussion. Within-piece statistical comparisons of motivic recognition per formal section revealed one more statistically significant pair in the electronic than the original version of the piece. This pair corresponds to section VIII, in which motivic recognition was equivalent for both versions of the piece (see Figure 5). Taking into consideration that motivic recognition was equal in both versions of section VIII and only slightly higher in section IX of *Anthèmes 1* than in that section of *Anthèmes 2* (see Figure 5), it seems reasonable to propose that the statistically significant difference in motivic recognition between sections IX and VIII that is exclusive to *Anthèmes 2* is likely to be due to differences in motivic identification between the two versions of the piece for section IX with respect to all other sections (rather than with respect to section VIII exclusively). This difference in motivic recognition in section IX can be explained by the relatively higher timbral blend among the musical materials and the blurring of the internal formal boundaries caused by the application of only one constant reverberating electronic effect in the electronic version of the section. As noted above, this constantly reverberating timbral homogeneity that fuses the motivic categories differentiates section IX from most other sections (with the exception of section V, which receives a similar electronic treatment), in which the electronic effects provide further timbral identity to the motivic categories, increasing the internal segmentability of the sections.

The idea that a single reverberating electronic effect applied to all the motivic materials within a section affects the recognition of those materials by obscuring the internal boundaries of the section can be further supported by a difference across versions in the pairwise comparisons of the proportion of motives recognized in section V with respect to that in the other sections. In *Anthèmes 2,* motivic recognition for section V was significantly lower than for sections I, II, and IV: $z \geq 3.37$, $p_{corr} \leq .02$. In *Anthèmes 1,* motivic recognition for section V was significantly lower than for section II only: $z \geq 3.23$, $p_{corr} \leq .03$. Figure 5 suggests that the difference between sections IV and V is augmented in the electronic version compared to the acoustic version, with lower recognition in section V and higher recognition in section IV for *Anthèmes 2.* Once again, this difference can be explained by the blurring of the internal sectional boundaries and the delimitation of the motivic materials caused by the application of a continuously reverberating electronic effect during section V—especially as opposed to the more clearly delimiting and not necessarily reverberating electronic effects associated with the motivic categories in section IV—in *Anthèmes 2.*

The second research question concerning effects of the organization of the musical materials and motivic features can be most directly addressed by examining motivic recognition during the sections of the piece that are the most and least predictable in terms of the order of presentation of the musical materials. As determined through the score-based analysis above, section II presents the same sequence of motivic materials five times, being the most predictable section of both versions of *Anthèmes*. Among all the sections with relatively high motivic recognition, section II gave the largest number of statistically significant pairwise comparisons between the proportion of motivic recognition in that section and in the remaining sections. For both versions of the piece, Wilcoxon Signed Rank tests revealed a significantly larger proportion of identification of motivic variations for section II than for sections V, VII, VIII, and IX: $z \geq 3.23$, $p_{corr} \leq .03$, for *Anthèmes 1*; and $z \geq 3.25$, $p_{corr} \leq .02$; for *Anthèmes 2.* We argue that this high motivic recognition associated with section II may be at least partly due to the repeating motivic patterns. In a piece where the motivic successions are generally difficult to predict and the motivic statements have unpredictable durations, it seems reasonable that listeners can more easily identify motivic variations when their order of presentation follows a repeating sequence of motivic materials. As discussed in connection with the score-based analysis, section VIII is the most unpredictable formal unit in the piece in the sense that the motivic materials appear to be ordered randomly. In *Anthèmes 1*, Wilcoxon Signed Rank tests indicated that motivic recognition for section VIII was significantly lower than that for sections II and VI: $z \geq 3.41$, $p_{corr} \leq .02$. In *Anthèmes 2*, motivic recognition for section VIII was significantly lower than that for sections I, II, and IV: $z \geq 3.36$, $p_{corr} \leq .02$. In both versions of the piece therefore, motivic recognition for the most unpredictable section (VIII) was significantly lower than that for the most predictable section (II). Section IV is also quite predictable in terms of motivic succession, because it states the same sequence of motives twice. Section VI is predictable in the sense that it consists of a palindromic pattern of only a few motives. Section I is unpredictable but also highly segmentable, especially in *Anthèmes 2*, where different electronic effects are applied to each motivic family. These results indicate that motivic materials are easier to identify when they are organized in a more predictable repeating sequence.

The predictability factor also appears to be affecting motivic recognition during section V (see Figure 5). As determined through the score-based analysis, the features of the motivic materials in this section are highly distorted. The motivic materials portray musical features not heard before in the piece and, consequently, become more unpredictable and more difficult to detect for the listener. Accordingly, we would expect lower motivic recognition for section V in both versions of the piece. In *Anthèmes 2*, section V is the section with the second lowest (after section IX) proportion of identification of motivic instances. As noted previously, motivic recognition was significantly lower for section V than for sections I, II, and IV in *Anthèmes 2*, but only for section II in *Anthèmes 1*. This difference in motivic recognition for section V with respect to the other sections in the electronic versus the purely acoustic version of the piece can presumably be explained not only by the motivic blurring caused by the constant reverberation applied to the electronic version of section V mentioned above, but also by the further distortion of the musical materials resulting from the specific electronic effects used during that section, which would make the succession of materials less predictable. With the exception of the Long Tone motive, all the motives in this section are enhanced with electronic effects that have not been used previously in the piece, presumably making the motivic features harder to identify. Specifically, in section V, the Melodic and Trill motives are greatly transformed as they are subject, for the first and only time in the piece, to an electronic process of randomization that disturbs the very succession of the component pitches of the motivic materials. Similarly, the frequency shift that very strongly characterizes the Scale motives from the opening of the piece disappears in section V, where those motives are heard in their plain acoustic version over the reverberating tails of the materials (from other families) preceding them. Based on these findings, we propose that the unpredictability (surprising appearance) or transformation of the features of musical materials interferes with the listeners' identification of those materials only when it reaches a certain (relatively high) degree of complexification.

Finally, the third research question concerning the effects of the general formal development of the music over time is directly addressed by the logistic regression analyses. In both versions of the piece, listeners' recognition of motivic variations decreased with each formal section, from the beginning to the end of the piece with the notable dip in section V noted above. In *Anthèmes 1*, analysis of the proportion of motivic identification on the nine formal sections showed that listeners were 22% ($e^{-0.25} = .78$)[2] less likely to identify motivic variations within each formal unit with respect to the immediately previous one: $b = -.25$, $p < .001$. This linear decrease in motivic identification across sections was remarkably similar for the longer version of the composition in which listeners were 21% ($e^{-0.23} = .79$) less likely to identify motivic variations within each formal unit with respect to the immediately previous one: $b = -.23$, $p < .001$. This decrease in motivic identification across sections was statistically the same for the two compositions, as shown by the nonsignificant interaction term (Formal Section × Piece) of a multiple logistic

[2] This shows the conversion of the value of *b* reported below to the odds ratio (.78 in this case), which in turn allows us to report the percentage of decrease in motivic recognition per formal unit (22% in this case). Here, the value of .78 means that the odds decrease by approximately 22%. The odds ratio is obtained by raising *e* to the power of the *b*.

regression analysis of proportion of motivic identification on Formal Section and Piece: $b = .02$; $p = .50$. These results support the idea that the overall formal development of the musical materials over time disturbs the listeners' ability to identify motivic variations. The similar effect obtained for the two versions of the composition in spite of their very different total durations suggests that it is not the mere passing of time (nor that the participants got more distracted, tired, or bored due to the repetitiveness of the task), but rather the evolution and organization of the musical materials over time that affect the identification of the motives. In *Anthèmes 2*, where all the constituent formal units are enlarged, the participant's recognition of the motives is affected at a slower pace in real time (time as succession of seconds), yet at the same pace in formal musical time (time as succession of formal sections). At least this is the case in the sense that the same decreasing effect in motivic recognition takes more than twice as many minutes in *Anthèmes 2* as in *Anthèmes 1*, yet over the same number of formal units in both versions of the piece. It is the overall temporal development of the musical materials and the way they delineate the formal structure that influences the listeners' perception of those materials.

General Discussion

Broadly, the experimental results reported in this paper indicate that the mere presence of a musical context can alter the perception of motivic similarity relations during listening, confirming previous reports on the perception of post-tonal music (Lalitte et al., 2004). Specifically, the findings presented above suggest that at least three contextual factors determined by characteristics of the musical structure—namely contrasts in surface features and the organization and development of the musical materials—shape the ways in which listeners perceive the motivic relations of musical compositions.

The effects of the addition of a context can be seen in a comparison of the results of Experiments 1 and 2 to those of Experiment 3. Experiments 1 and 2 both represent situations outside of the full (piece-specific) musical context, but the tasks that participants performed and the goals they tried to achieve in relation to the tasks were very different. The situation of Experiment 1 is broader than that of Experiment 2, because the participants in Experiment 1 had access to all the motivic families at all times during the experiment, whereas those in Experiment 2 listened to the motivic families in independent trials. The results obtained in each of these situations can be compared with the musically contextualized recognition of motivic materials observed in Experiment 3. A comparison of the clustering analysis obtained in Experiment 1 (Figure 2) with the recognition of motivic families during listening to the compositions in Experiment 3 (Figure 4) suggests that listeners' formation of motivic similarity relations is different when the motives are extracted from their musical context than when they are heard within that context. Whereas the Pizzicato and Long Tone motives were perceived as very similar to each other within their respective families outside the musical context, they were not among the most easily identifiable motivic types during listening to *Anthèmes*. In effect, the statistical analyses reported above showed that these two families were not recognized more than any of the other families and that the family that was recognized most easily in both versions of the piece was the Trill family. The situation was different for the motives of the Melodic family, whose similarity relations appeared to be weak both outside and within the musical context. Nevertheless, as reported above, the recognition of the Melodic family was more equivalent to that of the other families in *Anthèmes 2* than in *Anthèmes 1,* indicating that the apparent lack of internal similarity consistency of the family could be partly diminished by the contextual setting.

A descriptive comparison of the mean dissimilarities obtained for the motives in Experiment 2 (Figure 2) with respect to the identification of those motives in Experiment 3 further supports the idea that the similarity between musical motives can change when those motives are set in a musical context. For instance, during listening to *Anthèmes 1*, where the motivic models appeared in their exact version during the composition, L89 was recognized by a larger proportion of participants than was the model of the Long Tone family ($M = 0.65$ vs. $M = 0.45$), and P15 was recognized by a larger proportion of participants than was the model of the Pizzicato family ($M = 0.55$ vs. $M = 0.75$). These similarity relationships are reversed with respect to those obtained in Experiment 2 (see Figure 2). The reversal in the pattern of the observed trends seems to support the idea that motivic similarity relations are perceived differently within and outside the musical context. Overall, the differences between the results of Experiments 1 and 2 with respect to those of Experiment 3 discussed here support previous findings that the perception of musical materials is shaped by the specific musical context in which they are heard (Clarke & Krumhansl, 1990; Lalitte et al., 2004).

Continuing with the most important purpose of this paper—i.e., the specific characteristics of the musical context affecting the listeners' identification of motivic materials set in that context—musicians identified a significantly larger number of motivic variations during the formal sections of *Anthèmes* that are relatively easier to segment internally and based on predictable motivic successions or features than during sections that are difficult to parse and predict internally. Conversely, listeners' recognition of motivic variations significantly decreased as formal sections passed by. The rate of this decrease was the same for both versions of the piece, suggesting that the disturbance in motivic identification was more directly linked to the overall organization and development of the musical materials over time than to the mere passing of time or to listener fatigue and inattention. Altogether, these results indicate that musical events set in more predictable contexts (arising from either repeating motivic successions leading to those events or musical features more frequently associated with those events) or on more salient and contrasting contextual moments facilitate the recognition of motivic variations for listeners, whereas the overall formal development of the musical materials and their context over time disturbs the identification of those variations.

These findings are consistent with previous literature demonstrating the importance of surface contrasts, organization of the musical materials, and overall formal development of a musical work over time for the listening experience mentioned in the introduction. With respect to the relevance of surface features for music listening, previous literature has shown that, on the one hand, the characteristics of the motivic materials in terms of surface features facilitate their recognition within the composition (Clarke & Krumhansl, 1990; Deliège, 1989; Lalitte et al., 2004) and, on the other hand, contrasts in surface features are essential for parsing the structure of a composition during listening (Clarke & Krumhansl, 1990; Deliège, 1989; Deliège et al., 1996; Lalitte et al., 2004). Our results indicate that whereas the intrinsic surface features of the motivic materials are relevant for their classification (Experiment 1), it is the (contextually created) *contrast* in terms of surface features rather than the surface features themselves that facilitates the recognition of the musical materials (perception of motivic relationships) during listening to a piece of music (Experiment 3).

With regards to the organization of the musical materials, our results confirm previous findings that the order of presentation of the materials within a composition affects the listening experience of post-tonal music (Lalitte et al., 2004; Tillmann & Bigand, 1996), further suggesting that relatively predictable settings of musical materials facilitate the recognition of those materials for the listener. In this way, our report brings together previous findings related to the effects of intrinsic motivic features on similarity perception with those associated with the effects of broad contextual characteristics of the music on general aspects of music perception, as they indicate that the degree of contrast in surface features and the level of predictability of the organization of the musical elements affect the formation of motivic similarity relationships during real-time listening to complete post-tonal works.

Finally, our findings showing that the overall development of the materials and context over time disturbs the listeners' identification of motivic variations are compatible with previously reported evidence that the repetition of short musical materials interferes with the listeners' natural ability to identify those materials (Margulis, 2012). The concordance between our results and Margulis's on a decreasing effect of restatement of short motivic materials on their identification suggests that motivic repetition and similarity can shape at least certain aspects of the perception of musical works in similar ways. Considering that Margulis's work is associated with tonal repertoires and our results with post-tonal music, this perceptual functional resemblance between musical repetition and musical similarity would appear to be a relatively universal aspect of the listening experience of Western art music.

Based on the above and further supported by our conclusion that the musical setting affects the perception of motivic similarity relations, we would like to propose that musical context can perceptually blur the apparent (theoretically definable) dividing line between exact repetition and varied restatement of musical motives. This supposed blurring effect is likely to be an aspect of the music-listening experience in general, not only because the effect can be associated with tonal and post-tonal repertoires, but mostly because music listening is contextual in its very nature by means of its dependency on elapsing time. This presumed uncertainty of the difference between musical repetition and variation for the listener, the subordination of the perceptual distance between exact repetition and different degrees of transformation of the materials to diverse musical contexts, is perhaps one of the many factors that make repeating yet inevitably changing music-listening experiences transcendentally engaging.

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Correspondence concerning this article should be addressed to Cecilia Taher, Schulich School of Music, McGill University, 555 Sherbrooke Street West, H3A1E3, Montréal, Québec, Canada. E-mail: cecilia.taher@gmail.com

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